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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, April 27th, 1898.

The 124th meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS was held this date, at 12 West 31st Street, and was called to order at 8:30 P. M. by the Secretary.

THE SECRETARY:—The Vice-Presidents and Managers who are on the standardizing committee are engaged in quite an important session, and they will be in attendance later. Meanwhile we will proceed with the business of the evening, and if some gentleman would be kind enough to nominate a Chairman to act until the President arrives, I will entertain the motion.

MR. JOSEPH WETZLER:—I move that Mr. Leonard occupy the Chair temporarily in the absence of the President.

The motion was carried, and Mr. H. Ward Leonard took the Chair.

THE SECRETARY:—At the meeting of the Executive Committee this afternoon the following associate members were elected:

Name.	Address.	Endorsed by
ALLEN, WYATT H.	Care H. F. Allen, 202 California St., San Francisco, Cal.	Louis Duncan. H. S. Hering. Alex. Stratton.
FITZHUGH, WM. H.	Supt. Bay City Electric Plant, Bay City, Mich.	F. B. Rae. F. S. Hunting. Thomas Duncan.
FLEMING, JOHN BRECKENRIDGE,	Mill Superintendent and Cons. Engineer, Austin Mining Co., Austin, Nev.	R. W. Pope. Edw. Caldwell. W. F. C. Hasson.
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HOPKINS, N. S.	Ass't Engineer, General Electric Co. Box 825, Schenectady, N. Y.	H. G. Reist. A. L. Rohrer. C. P. Steinmetz.

LINDSAY, ROBERT	General Supt. The Cleveland Elec. Ill. Co., 717 Cuyahoga Building, Cleveland, Ohio.	M. C. Canfield W. S. Barstow. J. W. Lieb, Jr.
MUSCHENHEIM, FRED'K A.	Electrical Engineer, Western Electric Co., 57 Bethune St., residence, 41 W. 31st St., N. Y. City.	H. F. Albright. E. S. Keefer. Geo. A. Hamilton.
SCHLOSS, NEWTON L.	Consulting Engineer, 39 Cortlandt St., residence, Stuart House, N. Y. City.	Jos. Wetzler. T. C. Martin. R. W. Pope.
TOLMAN, CLARENCE M.	Electrical Engineer, with Edw. G. Stoiber, Silverton, Colo.	C. E. Doolittle. E. Friedlaender. H. G. Reist.
VINTEN, ERNEST STILES	Draughtsman, Walker Co., New Haven, Conn.; residence, 89 Pearl St., New Haven, Conn.	Chas. N. Black. H. McL. Harding. F. G. Daniell.

Total, 10.

The following paper on "An Economy Test of a Central Station" was presented by the Secretary in the absence of the author:

A Paper presented at the 124th Meeting of the American Institute of Electrical Engineers, New York, April 27th, 1898, Mr. H. Ward Leonard in the Chair.

AN ECONOMY TEST OF A CENTRAL STATION.

BY W. E. GOLDSBOROUGH.

Introduction.

During the summer of 1895, I made a study of one of the large electric lighting stations of Baltimore city, from an economic stand-point. A series of somewhat general observations, led, finally, to a decision to subject the plant to a number of rigid economy tests, to determine along what lines, if any, the method of operating the station could be modified to improve its efficiency. The tests were initiated largely as a matter of engineering interest; for the station, even at that time, was adjudged efficient. Arrangements for these tests were perfected about the end of the summer, and in the following pages is given an account of the more interesting matters that came to my notice during their progress.

Since 1895, the station has been so extensively improved, both as the result of these investigations and the natural growth of business, that the paper can hardly be said to be a record of the economic performance of any at present existing plant. New boilers have been added, as well as new engines. With but one or two exceptions the old engines have been refitted with new cylinders and valves, and the electrical units, dating as far back as the tests, have been so thoroughly renovated as to be practically new.

The station is to-day, without doubt, more efficient than in 1895, and the improvement is in a great measure due to the removal of the defects to which your attention will be called. Tests of the character of those discussed have an undoubted value, and there is many another plant to be studied and regu-

lated in virtually the same manner before it attains the maximum efficiency. A combination of boilers, engines and generators, however efficient they may be severally, do not necessarily produce an efficient station. Each station must be regarded as a special problem by the engineer, and must be studied as such.

The interest taken in investigations of this character by Mr. James Frank Morrison, general manager of the company controlling the station, made the tests possible, and it is through his kindness in consenting to the partial publication of the results obtained, that I am privileged to read before the INSTITUTE this abstract of my report. If the facts do not appear in some cases to bear out the conclusions, it must be remembered that it has been possible for me to embody in this paper only a small part of the original data.

Purdue University, La Fayette, Ind.,
March 1898.

THE STATION.

The West Pratt Street Station of the Edison Electric Illuminating Company of Baltimore city is situated on the north-west corner of Pratt and Penn streets, Baltimore, Maryland.

The station occupies a substantial one-story brick building that fronts on Pratt street and extends back 178 feet to King street. The general character of the building is very well illustrated in the ground plan and elevation of it that is contained in this paper. The Pratt street end contains the boiler plant; this room is 60 feet long and 67 feet wide. North of the boiler room is the engine room; it is 118 feet long and 60 feet wide.

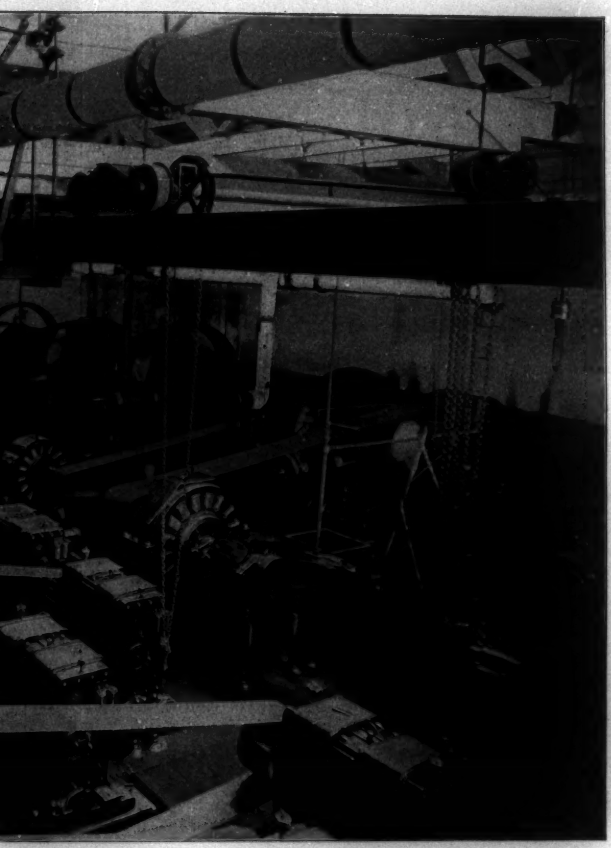
From Pratt street the station presents a pleasing appearance. Its front is rectangular, 35 feet high and broken by large double doors and windows.

The Boiler Room.—The boiler room contains nine water-tube boilers of the type manufactured by the Campbell and Zell Company which are arranged in four batteries of two each, with one large boiler in the south-west corner by itself.

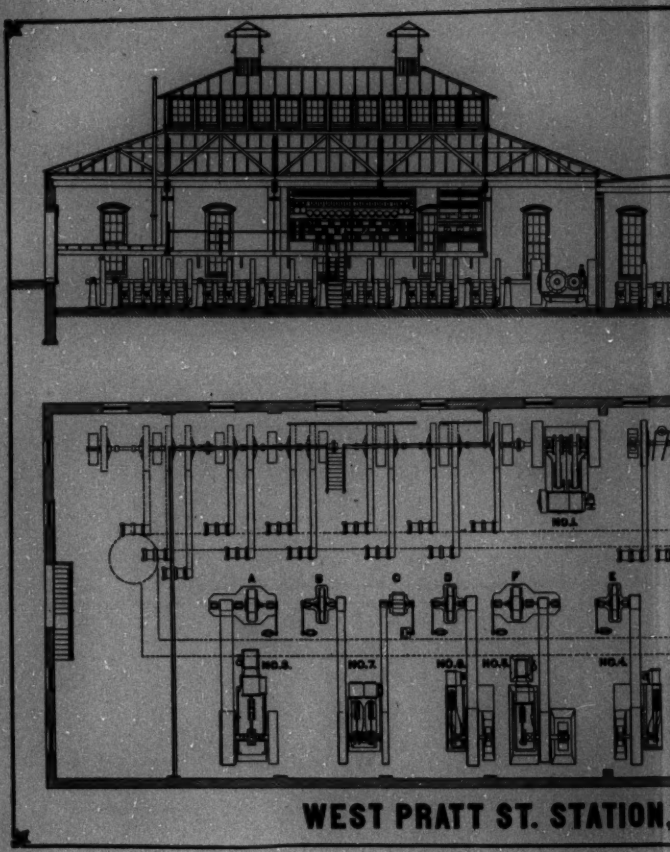
The boilers have a total rated capacity of 1,750 horse-power.

As shown by the ground plan of the station above referred to, the boiler plant is equipped with three large iron stacks. One of these receives the products of combustion from the furnace of boiler No. 1. Another is in the northwest corner of the boiler room and forms the continuation of the flues of boilers Nos. 2,

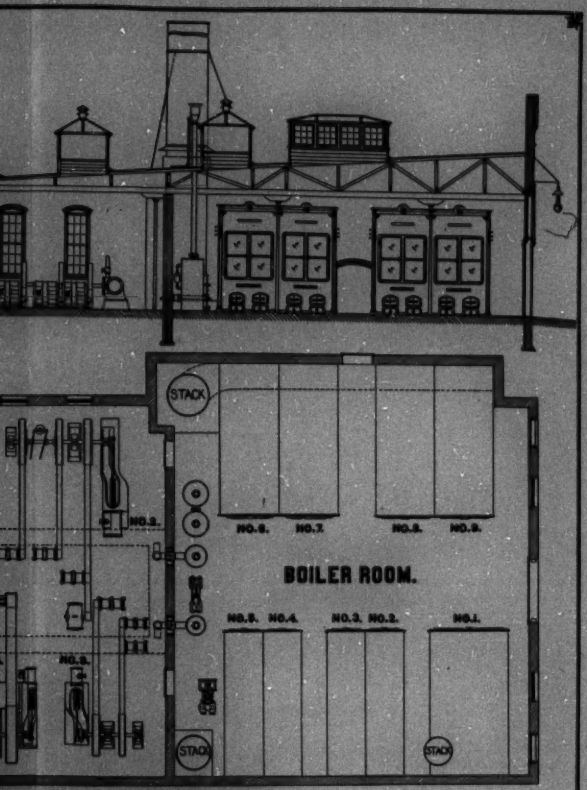
Engine Room, West Pratt Street



Street Station, Baltimore, Md.



WEST PRATT ST. STATION.



ON, BALTIMORE, MD.

3, 4 and 5. The third is in the northeast corner of the boiler room and is built to accommodate the large boilers, Nos. 6, 7, 8 and 9, on the east side of the station.

The location of the steam mains is not shown in the station drawing. A single 10-inch main extends along the west side of the boiler room over boilers Nos. 1, 2, 3, 4 and 5. It is carried through the north wall and terminates in a "straight line" centrifugal separator placed just inside the engine room. On the east side of the station a similar line of 16-inch pipe extends over and collects the steam from boilers Nos. 6, 7, 8 and 9. It is extended on into the engine room. The east and west steam mains are connected by a 10-inch pipe which runs parallel to the dividing wall just inside the boiler room. The cross main is equipped with a large stop valve and an equalizer connection.

The equipment of the boiler room also includes one 500 H. P. "national" feed water heater, one 500 H. P. "excelsior" heater and purifier and one 1500 H. P. double open and closed feed water heater made at the Bass Foundry and Machine Works.

There are three duplex pumps at the north end of the boiler room, where the heaters are also placed. The steam cylinders of these pumps are 12″ x 12″ and the water cylinders 7″ x 12″

As a rule it is found that one pump is sufficient to supply the boilers, and during the tests made upon the station, only one pump was used. The feed water flows from the city mains directly to the heaters in which it is heated by the exhaust steam from the engines. It is drawn from the heaters and forced into the boilers by the pumps. During the tests the heaters were found to be very effective. They do not apparently increase the back pressure in the exhaust mains and yet save over 11 per cent. of the fuel.

The Engine Room.—The newer part of the station building north of the boiler room contains the engines and the electrical machinery. The floor of this room is about level with the ground. The foundations of the engines all extend above the floor and there are no wheel pits, etc. in the station. The aggregate rating of the engines is 2065 H. P.

The piping between the engines and boilers is ample in its dimensions. Engines Nos. 1, 2, 3, 5 and 8 are on the east side main. This main is constructed of 16-inch pipe up to the point where the supply pipe of No. 1 engine is connected.

Beyond this point it is reduced to 10-inch pipe and is carried over to the west side of the station; it is then extended north over engines Nos. 5 and 8. Where the east main crosses the middle of the station a "straight line" centrifugal separator has been inserted. This is the only separator on this line of pipe.

The pipe connections between engines Nos. 1, 2, 5 and 8, and the east main are quite direct and short; the connection to No. 3 is however, necessarily long; it extends entirely across the station.

Engines Nos. 4, 6 and 7 are connected to the west side steam main. This main extends almost due north from the boiler room and is composed of 10-inch pipe throughout its entire length.

The exhaust mains extend north and south underneath the floor. They connect directly with the heaters, and all waste steam not condensed by the feed water is discharged through exhaust heads into the air. All of the engines exhaust into these mains except engine No. 1, which exhausts directly into the atmosphere through an exhaust head.

The normal steam pressure at which the engines are operated is 130 pounds by gauge. The entire plant is non-condensing.

The station is equipped with electrical machinery designed to supply 13,000 16 C. P. incandescent lamps and 1,420 2,000 C. P. arc lamps. The arrangement of the units is shown on the ground plan of the station. They are all belted to the engines.

The dynamo leads are carried to the switchboard, which is raised nine feet above the floor of the station, through subways underneath the floor. From the switchboard the leads are carried out of the station on suitable racks through the skylight that covers the greater portion of the roof of the engine room.

A very good idea of the appearance of the station and the general arrangement and setting of the machinery can be obtained from the cut of the engine room. The cut brings out the arrangement of the steam piping and wiring very clearly.

The Arc Lighting Plant.—In the arc lighting plant, the usual American practice of transmitting power to numerous dynamos from one engine by means of shafting and belting is followed. The entire equipment is divided into three sets.

Engine No. 1, which is a 600 H. P. horizontal cross-compound high-speed Ball and Wood engine, is directly connected to a line shaft that extends along the east side of the station, and to which

twelve 80-light Wood 2,000 C. P. arc light machines are belted. Each of these dynamos will safely develop 38.4 K. W. or 51.47 H. P., making a possible total load of 618 H. P. for the engine, over and above the friction load due to the line shafting.

Engine No. 2 is also directly connected to a line shaft extending along the eastern wall of the station. The engine is a simple four valve horizontal high-speed Russell engine of 170 H. P. and drives a 10 K. W. 500-volt Wenstrom generator and three 80-light Wood 2,000 C. P. arc light dynamos, which are all belted to its line shaft. The total maximum rated electrical output of this equipment is 168 H. P.

Engine No. 3 is a 125 H. P. simple single valve, high-speed horizontal Russell engine. It drives two 80-light and one 60-light Wood 2,000 C. P. arc light dynamos that are belted to pulleys on a short extension of the engine shaft. The total normal rated output of this equipment is 141.5 E. H. P.

The normal current output of the arc machinery is 9.6 amperes. The practice at the station, however, is to regulate the machines at about 9.5 amperes, and this current value was used during the tests, except in the case of machines Nos. 4 and 6, which supply the arc motor circuits and are operated above their normal capacity at 10 amperes.

The Incandescent Plant.—The single-phase alternating current system is exclusively employed for the distribution of power to the incandescent lighting circuits. A uniform pressure of 1000 volts is supplied to the distributing mains, and this is reduced by means of transformers to 50 volts at points where it is supplied to consumers.

To meet the increasing demands upon the station and to admit of the most economical adjustment of the load under existing conditions the incandescent plant has been enlarged from time to time until at present it comprises five distinct equipments each operated by a separate engine. The arrangement of this machinery is very well exhibited in the cut of the ground plan and side elevation of the station contained in this paper. Referring to it:

Alternator A, is a 150 K. W. Wood machine compounded for 1000 volts. It is operated by a 300 H. P. tandem compound "ideal" engine.

Alternator B, is a 100 K. W. compound Slattery machine.

Alternator C, a 50 K. W. Thomson-Houston machine, both of which are operated by a 300 H. P. cross-compound Ball and Wood engine.

Alternator D, is a 100 K. W. Slattery machine, driven by a 145 H. P. Buckeye engine.

Alternator E, is also a 100 K. W. Slattery machine and is driven by a 145 H. P. Buckeye engine.

Alternator F, is a 150 K .W. compound Wood machine and is driven by a 300 H. P. Ide engine.

As the diagram indicates, all of the alternators are belted, solid leather belts being used. Their exciters are supported on separate bases, and are belted to pulleys placed on the collector ends of the shafts of the alternators.

The Tests.

The tests that were made upon the station took place during the last week in August, and the first week in September, 1895.

In planning for the tests *no effort was made to improve the condition of the plant in any respect.* The engines and other machines were operated just as they had been running during the months previous, and absolutely no modifications were made in the methods of adjusting the load to the various units, in the way in which the boiler plant was handled, or in the usual control of the water and coal supply; except on Sept. 1st and 2nd as explained later. The station employees were in no wise instructed to modify their habitual practice, and they were at all times left perfectly free to perform their accustomed duties.

In carrying out the details of the tests, in the construction of additional apparatus, the calibration of instruments and the fitting and adjustment of the same, in fact, for the perfection of all the varied requirements of so large an undertaking, competent extra help was employed.

Every effort was made to have each detail of the general plan accurately outlined, worked up and perfected. For the measurement of the water supply a large weir was built on the north-east corner of the boiler room roof almost directly over the 1500 H. P. feed water heater. Measurements were taken of the water level in the weir at 5 minute intervals throughout the entire period of the tests with a Boyden hook gauge, and a continuous record was also obtained with a very sensitively adjusted chronograph. As a check upon these readings, the water-meter, through which all the water passed that entered the station, was read at 15-minute intervals. Furthermore every water connection, through which leakage could possibly occur, was tested, and made water tight if found imperfect.

In figuring up the amount of water that was supplied to the boilers, the levels shown by the hook gauge and the chronograph records were checked against one another, and the chronograph records were all integrated with an Amsler planimeter. The results that were obtained in this way were then compared graphically with the water meter readings. The weir and water meter curves follow one another quite closely, and show that up to the rate of flow of 2200 pounds of water per hour the water meter registers *less* than the true amount of water, but that over that rate it measures *more* than the true amount of water.

The scales used in measuring the coal were made by Fairbanks, and their accuracy was assured by testing them with a block of iron, the weight of which had previously been ascertained on the standard scales at the United States Sub-treasury.

Each barrow of coal was passed over the scales and balanced accurately for 400 pounds of coal before being carried into the station.

All the steam gauges used in connection with the tests, were standardized by comparing them with a *new* Thomson and Robertson gauge testing set. The thermometers used in making calorimetric tests of the quality of the steam had been calibrated previous to the tests and were calibrated again immediately after the tests. These calibrations were found to correspond. The calorimeters used were three carefully constructed throttling calorimeters and one Carpenter separating calorimeter. The pyrometer used in measuring the temperature of the flue gases was calibrated by inserting it into a steam pipe and comparing its readings with determinations made of the temperature of the steam from the readings of two calibrated gauges connected to the same steam pipe. During the tests, each steam cylinder of the engines and the pump was equipped with a steam indicator, and proper indicator riggings were fitted up to ensure the accuracy of the cards taken. Engines Nos. 1, 5, 7 and 8 were equipped with two-way cocks in connection with the indicator fittings, but on the other engines, valves placed on either side of the indicator had to be relied upon when taking cards from the opposite ends of the cylinders.

The speed of each of the engines was taken every 15 minutes with the usual form of Starrett hand speed indicator. The speed of engine No. 1 was always taken at the time the indicator cards were made, and the speeds of the other engines immediately

thereafter. This method is not so exact as that of using tachometers or constant speed counters, but owing to the fact that there were no *sudden* changes in the load on any of the engines, the plan adopted was considered sufficiently accurate.

Testing Instruments.—For taking the record of the output of the arc dynamos quite an amount of special wiring was necessary. Three standard high range Weston voltmeters were available for determining voltage readings. Three tables were therefore constructed with a double row of mercury contacts arranged along one side of the top. The tables were nailed to the floor and connections made between the terminals of each of the arc machines and a pair of the mercury contacts. One of the standard voltmeters was placed on each table, and was used to take the voltage readings of the machines connected to that table by successively inserting a flexible insulated connector into the mercury contacts.

As it was impossible to provide ammeters for all the arc circuits, one standard Weston direct current ammeter was used for testing all of them. A test was made of all the circuits every 15 minutes during the five minutes immediately preceding the time for taking the general station readings. It was found that the currents remained practically constant as the loads were subject to only slight variations.

The voltmeters and alternating current indicators employed on the alternator circuits are of the older types supplied by the makers of the machinery, but the ammeters on the distributing mains are of the most improved Wood pattern. Wirt lightning arresters are used on all the distributing circuits.

The arrangement of the switchboard connections is such that it is possible to connect any one alternator to only about half of the distributing circuits at any one time. The changing of a circuit from one alternator to another is effected by the manipulation of a series of double-throw switches, which when placed in a certain order to bring a proper load on one alternator, may prevent the completion of the combination of connections that would be most advantageous in loading some other machine. The restrictions imposed by the switchboard have the effect at times of causing the operation of a dynamo which could be dispensed with were a thoroughly flexible system of switchboard connections provided. The remodelling of the board would in fact greatly facilitate the economical operation of this portion of the

station, and would result in a considerable saving in the operating expenses. This point is well brought out in the tests made upon the plant.

In this station each alternator is operated entirely independent of any other, *i. e.*, parallel working of the machines is not attempted.

Calibration of Instruments.—To ensure the thorough reliability of the readings of the electrical switchboard instruments they were all carefully calibrated by comparing them with standard Weston instruments obtained especially for this purpose direct from the Weston Electrical Instrument Company.

The calibration of the switchboard voltmeters was effected by connecting a standard 110-volt Weston alternating and direct current voltmeter, and a multiplying coil that multiplied its readings by 10, directly across the 1,000-volt mains and comparing its readings with the readings of the switchboard instrument undergoing calibration. The switchboard instruments were not removed from their normal positions or their connections disturbed in the least, the variations in the voltage between the leads to which the instruments were attached being produced by changing the field excitation of the respective dynamos to which they were connected.

The calibrations of the switchboard ammeters were effected by employing an indirect, though perfectly successful, method. A large non-inductive resistance was constructed by stretching a quantity of No. 17 B. & S. gauge german silver wire on a number of 12-foot boards by passing it around porcelain insulators screwed to the boards. These resistances were then connected to an old arc light switchboard so that any number of them could be connected either in series or in parallel as the case might require. A switch was fixed so that the arc switchboard with the resistances could be short-circuited when not in use. The lead that connected the ammeter to be tested with its dynamo was disconnected and led to one side of the arc switchboard just described. After being made to pass through the non-inductive resistance of the board, the circuit was then connected to the current terminals of a standard Weston wattmeter. From the other current terminal of the wattmeter the circuit was connected to the ammeter to be tested. The ammeter was in this way placed in series with the non-inductive resistance and the current coil of the wattmeter. The voltage terminals of the wattmeter were

connected as a shunt around the non-inductive resistance, and a standard Weston voltmeter was arranged to measure the fall of potential through the non-inductive resistance, *i. e.*, it was also shunted around the resistance. In this way means were provided for measuring the power absorbed in the resistance by the wattmeter, and by dividing the wattmeter reading by the reading of the standard voltmeter the current flowing through the resistance and therefore through the switchboard ammeter tested, could be determined. By varying the load on the alternators the current readings of the ammeters were varied over the working range of the respective machines, and the readings of the ammeters were then compared with the determinations of the true values of the currents made as described above.

The calibration tests indicated that the instruments were not very far out, and but a slight correction in the results recorded during the tests was necessary. The necessary correction was made in every case.

Determination of Power Factors.—On transformer circuits the power factor is not a constant, as the inductance of the line varies with the number of incandescent lamps that are turned on. Under ordinary circumstances, however, the power factor for any given circuit will be very nearly a constant for any given load on the circuit, whatever be the distribution of the load between the several secondary circuits supplied; it is therefore possible to plot a curve showing the relation of the apparent power to the real power for all loads for any given circuit, and having once obtained this curve the real power can always be obtained from the apparent power by reference to it.

As the standard Weston wattmeter already referred to was obtained on the 4th of September, and all tests had to be completed before the 8th of September, it was impossible to determine the power factors for each of the circuits. It was possible however, to make these determinations collectively for the several circuits supplied by "A" and "F" alternators during their all-day runs on September 6th and 7th respectively, and from the results so obtained a very fair estimate of the power factors that should be used for the tests has been arrived at.

The power factor varies between 88.2 and 99.6 per cent., with the majority of the points falling at about 91 per cent.

These results are for the *day load*. After carefully reviewing the results of both of the tests of the incandescent plant, and

making numerous comparisons, it was decided to use the power curve for all determinations of the *real power* developed by the several alternators, between 7 A. M. and 6 P. M., and 12 P. M., and 7 A. M., on each day on which tests were made, but between 6 P. M. and 12 P. M. a factor of *100 per cent.* was used for all circuits. This course was followed, since between 6 P. M. and 12 P. M., the load on the station is very heavy and therefore all the factors very high.

Any error that may be introduced by this procedure is slight at most, as the uniformity of the efficiencies obtained during the day and night runs plainly indicates.

Duration of Tests.

The first test began at 7 A. M. on August 31st and continued until 7 A. M. on September 1st. During this time measurements were taken, as already described, on all the machinery and boilers operated in the station. During the hours of the heavy load, between 6 P. M. and midnight, 41 men were employed in taking readings.

The second test began at 5:45 P. M. on September 1st, and continued till 5 A. M. on September 2nd. This test was made to determine the efficiency of engine No. 1 and boilers Nos. 6, 7 and 8. It was made on Sunday night, because, owing to the arrangement of the steam piping and the large load on the station at other times during the week, the necessary adjustment of the boiler plant could only be effected at this time. For this test 24 men were employed.

The third test began at 7 A. M. on September 7th and ended at 7 A. M. on September 8th. It was carried out in all respects like the first test. The maximum number of men engaged in taking readings at any one time on this day was 42.

Each of the tests was thoroughly successful, and although a very severe storm raged during the afternoon of August 31st, the test made on that day was not seriously interfered with. On the contrary, the men showed remarkable coolness in carrying on their work quietly and in an orderly manner in the face of considerable danger.

The plan adopted for recording the results was to take simultaneous readings every 15 minutes from all the instruments, etc., at a signal given by blowing a steam whistle in the engine room.

The Boiler Tests.

The Boilers :—The boiler plant of the station is composed of four batteries of two boilers each, and one odd boiler. They are all of the water tube type and of the same general design, as they were built by the same company, but on account of having been placed in the station at different times, they differ somewhat from one another in the minor details of their construction.

The data on the dimensions and capacity of the boilers that are given in table 1 were obtained from the representatives of the Campbell and Zell Company, the makers of the boilers, and they have been checked up with the drawings from which the boilers were made and by measurements taken in the boiler room.

Boiler No. 1 was the first to be placed in the station; it is a double boiler and is rated by the builders, as a 250 H. P. boiler. The present practice of the builders, as stated on page 59 of their catalogue, is to rate their boilers on the basis of "11½ square feet of heating surface in the water tubes alone," per horse power. If this method of determining the capacity of boiler No. 1 is followed, its rated capacity figures out to be 186.5 horse power. (See item 34, table 1.)

Boilers Nos. 2, 3, 4 and 5 occupy space on the west side of the boiler room and form batteries 2 and 3. They were placed in position some time after boiler No. 1, and are of a more recent design. Their capacity by the original builders rating is 125 H. P. per boiler, and on the basis of "11.5 square feet of heating surface in the tubes alone," it is 61.2 H. P. per boiler.

Boilers Nos. 6, 7, 8 and 9 are of quite recent design. The builders rate them at 250 H. P. each, but their capacity figured on the 11.5 square feet of heating surface basis is 242.6 H. P. per boiler.

Summing up we find that the total rated capacity of the boiler plant is 1750 H. P., or 1401.7 H. P. when figured on the basis of 11.5 square feet of heating surface per horse power, *in the tubes alone*.

On the mornings of each of the days on which the tests were made, the fires under boilers 6, 7, 8 and 9 were burning bright, were clean and all the ashes had been removed from the ash pits.

The ashes that accumulated during the 24 hours' run were carefully weighed before being wet, and the fires burning at the end of the tests were left as nearly as possible in the same condi-

tion as were those which were burning when the tests began. In determining the moisture in the coal, samples were selected from the coal yard and dried.

In determining the moisture in the coal used Aug. 31st, account had to be taken of the fact that there was a heavy rain fall in the afternoon. In view of the fact however, that another determination was made of the moisture in the coal on the next day,

TABLE 1.

Designation of the Boilers by the Edison Elec. Illuminating Co.	Boiler. No. 1.	Batteries. No. 1 and No. 2.		Batteries. No. 3 and No. 4.	
	No. 1.	Boilers 2, 3, 4 and 5.		Boilers 6, 7, 8 and 9.	
1. Length of tubes	16′	14′	14′	18′	18′
2. Tubes per section	4	2	2	4	4
3. No. of sections	32	24	24	37	37
4. Total No. of tubes, per boiler.	128	48	48	148	148
5. Diameter of tubes	4″	4″	4″	4″	4″
6. Length of water drums	18′	16′	16′	20′	20′
7. No. " " "	4	1	1	2	2
8. Diameter of water drums	18″	18″	18″	30″	30″
9. Sq. ft. heating surface per tube.	16.752	14.658	14.658	18.846	18.846
10. " " " " " sect	67.008	29.316	29.316	73.384	71.384
11. Total sq. ft. heating surface in tubes	2144.3	703.58	703.58	2789.2	2789.2
12. Sq. ft. heating surface per drum.	75.74	67.34	67.34	139.72	139.72
13. Total sq. ft heating surface in drums	302.96	67.34	67.34	279.44	279.44
14. Total sq. ft. heating surface	2447.3	770.92	770.92	3068.6	3068.6
15. Width of grate surface in ins.	120	47	47	90	90
16. Length of grate surface in ins.	78	72	72	84	84
17. Area of grate surface in sq. ft.	65	23.52	23.52	52.5	52.5
18. Ratio heating to grate surface.	37.65	32.77	32.77	58.43	58.43
19. Ratio heating to super-heating surface					
20. Super-heating surface					
21. Length of tubes, inches	156	138*	138*	177.5	177.5
22. No. of tubes	16	6*	6*	12	12
23. Diameter of tubes	4″	4*	4*	4″	4″
24. Sq. ft. heating surface per tube.	11.52	12.03*	12.03*	15.479	15.479
25. Total heating surface sq. ft.	184.32	72.18*	72.18*	185.75	185.73
26. Area cyl. one water drum sq. ft.	84.18	75.36	75.36	157.08	157.08
27. Super-heating area one water drum sq. ft.	9.04	8.02	8.02	17.36	17.36
28. Total for water drums sq. ft.	36.16	8.02	8.02	34.72	34.72
29. Length of steam drum, inches.	120	47	47	90	90
30. Diam. of steam drum, inches.	42				
31. Area of cylinder of steam drum sq. ft.	109.96	42*	42*	42	42
		43.1	43.1	82.47	82.47
32. Total super-heating surface	330.44	123.3	123.3	302.04	302.04
33. Horse-power allowing 11.5 sq. ft. of heating surface per H. P. in tubes alone	186.5	61.2	61.2	242.6	242.6
34. Horse-power allowing 11.5 sq. ft. of heating surface per H. P. in tubes and drums	212.8	67.02	67.02	267.	267.
35. Rated horse-power of boilers.	250.	125.	125.	250.	250.

*No positive data—approximated. Data is given per boiler.

it was possible to approximate the true percentage of moisture for the whole test with a considerable degree of accuracy.

The engineer's and the assistant engineer's reports show that the same firemen were on duty during the same hours on Aug. 31 and on Sept. 7. So that the results of the two day's tests are as thoroughly comparable from this stand-point as from any other.

The Boiler Test of August 31st:—This test began at 7 o'clock on the morning of August 31st and ended just 24 hours later. During this time the station was operated according to the usual daily schedule and no attempt was made to modify or better the usual conditions in any way.

The log of the boiler test is exhibited graphically in Fig. 1. Table 2 contains the data and calculated results upon which the report of the boiler test given in table 4, column 1, is largely based, and it explains the method used for determining the true average grate surface, heating surface and horse power rating of the boilers. Such a process had to be resorted to in view of the

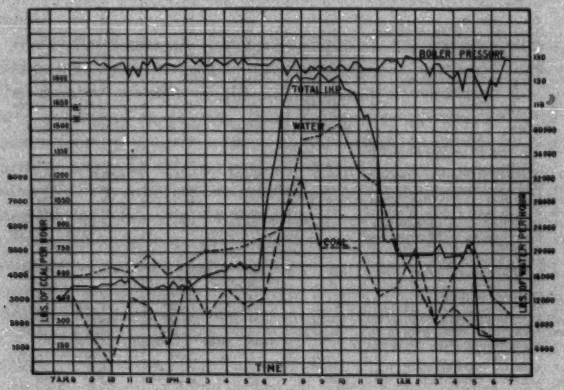


FIG. 1.—Pratt Street Station, Graphical Record, Aug. 31, Sept. 1, 1895.

fact that all of the boilers were not in service all of the time. All of them were in service some of the time, and some of them were in service all of the time.

In view of the fact that great care was taken during the trial to have the coal and water supplied to the boilers in just the proportions that were necessary to meet the demands made upon the boilers by the engines, it has been thought advisable to work up the data of the boiler trial over the portions of time during which certain of the boilers were in continuous service, in order that an estimate might be gained of the relative evaporative efficiency of the different batteries.

In column 3 of table 4 are presented the results of the boiler trial between 7 A. M. and 1 P. M. on Aug. 31. During this time boilers 6, 7, 8 and 9 were continuously in service and operated alone.

In column 5 of table 4 are presented the results of the boiler trial between 3 P. M. of August 31st and 1 A. M. of September 1st. During this time the entire boiler plant was in continuous service.

In column 7 of table 4 the results of the boiler trial during the hours of the heavy load, between 7 P. M. and midnight of Aug. 31 are given.

These results, when studied in connection with those of the trial of Sept. 7, reveal much valuable information regarding the efficiency of the boilers as well as the most economical methods to be employed in operating the boiler plant.

The Boiler Test of Sept. 7th.:—The boiler test of Sept. 7th was similar in all its details to the tests made on Aug. 31.

The records of the test are contained in tables 3 and 4. By comparing the data in tables 2 and 3 it will be found that the boilers were cut in and out on Sept. 7, at almost the same hours as the same boilers were cut in and out on Aug. 31. For example the trials were commenced on both days with boilers 6, 7, 8 and 9 in service; at about 2:20 P. M., boilers 1, 2, 3, 4 and 5 were cut in and from that time on till 1:45 A. M. of the second day of each test, none of the boilers were cut out. This fact has made it possible to report the trials in precisely the same manner. The general report for the entire 24 hours is given in table 4, column 2. The results here recorded are based upon boiler log and the average square feet of grate surface, water heating surface and horse power rating that are given in table 3. The "average rated horse power" is based upon the basis of the builders horse power rating, and the "average real horse power" is determined upon the basis of 11.5 square feet of heating surface in the boiler tubes being the equivalent of one horse power. This explanation also applies to items 44—44.5—45 and 45.5 of the boiler reports.

A report on the trial of boilers, 6, 7, 8 and 9 between the hours of 7 A. M. and 1 P. M. of Sept. 7 is set forth in column 4 of table 4. During this time the boilers mentioned were the only ones in service.

TABLE 2.

RECORD OF TEST OF STATION. AUGUST 31 AND SEPTEMBER 1, 1895.

Table showing the number of hours during which the respective boilers were in service.

No. of Boilers.	Hour started. Aug. 31.	Hour stopped. Sept. 1.	No. of hours in service. Hrs.	Min.	Sq. ft. grate surface.	Sq. ft. grate surface hours.	Sq. ft. water heating surface.	Sq. ft. water heating surface hours.	Rated Horse-power.	Rated Horse-power hours.	Real Horse-power.	Real Horse-power hours.
1	2:15 p. m.	3:25 a. m.	13	10	65.	855.40	2447.3	32206.46	250	3290.00	186.5	2454.34
2	" "	2:50 "	12	35	23.52	295.88	770.92	9698 17	125	1572.50	61.2	769.896
3	" "	2:50 "	12	35	23.52	295.88	770.92	9698.17	125	1572.50	61.2	769.896
4	" "	1:45 "	11	30	23.52	270.38	770.92	8865.58	125	1437.50	61.2	703.80
5	" "	1:45 "	11	30	23.52	270.38	770.92	8865.58	125	1437.50	61.2	703.80
6	7:00 a. m.		24		52.5	1260.00	3068.6	73646.40	250	6000.00	242.6	5822.40
7	" "		24		52.5	1260.00	3068.6	73646.40	250	6000.00	242.6	5822.40
8	" "	5:45 "	22	45	52 5	1194.37	3068.6	69810.65	250	5687.50	242.6	5519.15
9	" "	5:30 "	22	30	52.5	1181.25	3068.6	69043.50	250	5625.00	242.6	5458.50
Totals						6883.54		355480.98		32621.50		28024.182

Average square feet grate surface $\frac{6883.545}{24} = 286.73$

Average square feet water heating surface $\frac{355480.98}{24} = 14811.7$

Average rated horse-power $\frac{32621.50}{24} = 1359.2$

Average real horse-power $\frac{28024.182}{24} = 1167.66$

TABLE 3.

Record of Test of Station. September 7–8, 1895.

Table showing the number of hours during which the respective boilers were in service.

No. of Boilers.	Hour started Sept. 7.	Hour stopped Sept. 8.	No. of hours in service. Hrs.	Min.	Sq ft. grate surface.	Sq ft. grate surface hours.	Sq. ft. water heating surface.	Sq. ft. water heating surface hours.	Rated Horse-power.	Rated Horse-power hours.	Real Horse-power.	Real Horse-power hours.
1	2:25 p. m.	6:00 a. m.	15	35	65.	1012.895	2447.3	38128.93	250	3895.75	186.5	2996.229
2	" "	3:15 "	12	50	23.52	301.76	770.92	9890.90	125	1603.75	61.2	785.196
3	" "	" "	12	50	23.52	301.76	770.92	9890.90	125	1603.75	61.2	785.196
4	" "	3:20 "	12	55	23.52	303.64	770.92	9962.57	125	1613.75	61.2	794.892
5	" "	" "	12	55	23.52	303.64	770.92	9962.57	125	1613.75	61.2	794.892
6	7:00 a. m.		24		52.5	1260.00	3068.6	73646.40	250	6000.00	242.6	5822.4
7	" "		24		52.5	1260.00	3068.6	73646.40	250	6000.00	242.6	5822.4
8	" "	12:45 "	17	45	52.5	931.87	3068.6	54787.15	250	4437.50	242.6	4306.130
9	" "	5:50 "	22	50	52.5	1168.57	3068.6	70467.07	250	5625.00	242.6	5538.558
Totals.....						6874.135		350382.89		32393.25		27555.913

Average square feet grate surface $\frac{6874.135}{24} = 286.45$

Average square feet water heating surface $\frac{350382.89}{24} = 14599.7$

Average rated horse-power $\frac{32393.25}{24} = 1845.71$

Average real horse-power $\frac{27555.913}{24} = 1147.32$

In column 6 of table 4 the results contained in the boiler log between the hours of 3 P. M. Sept. 7, and 1 A. M, Sept. 8, are given in the form of a report on a test of all the boilers in the station operating at one time, and in column 8 a similar record is reported of the economy of the plant when working under the heavy load that comes on the station between 7 P. M. and midnight.

The graphical records of this boiler trial are presented in Fig. 2 and for the value of the comparison the total indicated horse power curve is plotted, in connection with the curves that pertain purely to the boiler tests.

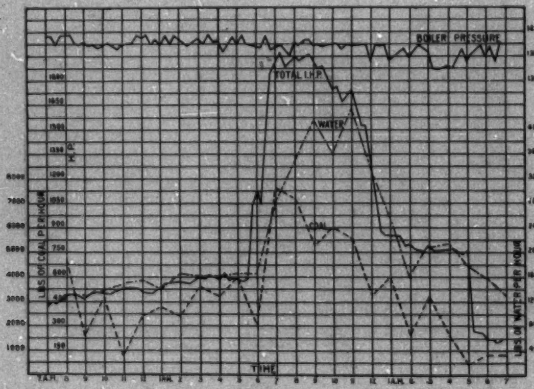


FIG 2.—Pratt Street Station, Graphical Record, Sept. 7, 1895.

REVIEW OF THE BOILER TESTS.

As the tests and portions of tests that have been reported amount to nine in all, and require a table containing ten columns, it is necessary to refer to the tabulated quantities by numbers.

The signification of the numbers is as follows:

1. Number of boilers in service.
2. Duration of trial.
3. Boiler pressure by gauge.
13. Temperature of steam.
15. Temperature of feedwater leaving heater.
15.5 Temperature of feedwater entering heater.

17. Per cent. of moisture in coal.
19. Per cent. of refuse in coal.
24. Per cent. of moisture in steam.
31. Water actually evaporated per pound of dry coal, from actual temperature and pressure.
32. Equivalent water evaporated per pound of dry coal, from and at 212 degrees Fah.
33. Equivalent water evaporated per pound of combustible from and at 212 degrees Fah.
35. Dry coal actually burned per sq. ft. of grate surface per hour.
39. Water evaporated from and at 212 degrees Fah. per sq. ft. of heating surface per hour.
43. Commercial horse power.
44. Horse power by builder's rating.
44.5 Horse power on a basis of 11.5 sq. ft. of heating surface in the tubes per horse power.
45. Per cent. of item 43 below item 44.
45.5 Per cent. of item 43 below item 44.5.

TABLE 4.

BOILER TEST DATA.

0	1	2	3	4	5	6	7	8	9
Number	7 A. M. Aug. 31, to 7 A. M. Sept. 1.	7 A. M. Sept. 7, to 7 A. M. Sept. 8.	7 A. M. Aug. 31, to 2 P. M. Aug. 31,	7 A. M. Sept. 7, to 7 P. M. Sept. 7.	3 P. M. Aug. 31, to 1 A. M. Sept. 1.	3 P. M. Sept. 7, to 1 A. M. Sept. 8.	7 P. M. Aug. 31, to 12 M.M.	7 P. M. Sept. 7, to 12 M.M.	6 P. M. Sept. 1, to 5 A. M. Sept. 2.
1	ALL AT TIMES.		6, 7, 8, and 9.		1, 2, 3, 4, 5, 6, 7, 8, 9.		1, 2, 3, 4, 5, 6, 7, 8, 9.		6, 7, and 8.
2	24	24	6	6	10	10	5	5	11
7	126	134	127	136	127	135	126	135	126
13	353	357	352	357	354	357	353	358	353
15	200	200	207	200	205	200	200	200	191
15.5	71.3	70.5	71.4	70.8	71.3	70.5	71.3	70.0	71.4
17	13.8	6.26	3.1	6.26	13.8	6.26	13.8	6.26	3.1
19	10.4	10.	10.4	10.	10.4	10.	10.4	10.	10.5
24	.81	.97	.70	.83	.90	1.04	.95	.91	.87
31	7.18	7.04	8.33	5.80	7.23	6.48	7.88	7.40	10.1
32	7.59	7.46	8.87	6.15	7.77	6.86	8.34	7.84	10.7
33	8.32	8.29	9.90	6.83	8.77	7.69	9.31	8.71	12.0
35	10.4	10.6	9.53	11.6	10.8	10.9	12.5	13.8	11.4
39	1.53	1.54	1.46	1.22	1.79	1.73	2.11	2.24	2.09
43	655	654	515	430	900	895	1116	1158	557
44	1359	1359	1000	1000	1750	17.50	1750	1750	750
44.5	1168	1147	970	970	1402	14.02	1402	1402	728
45	51.7	51.8	48.5	56.6	48.5	49.0	36.2	33.8	85.7
45.5	43.8	43.9	46.9	55.2	35.7	36.1	90.5	17.5	25.4

The quality of the coal fired to the boilers during the tests was only fair, and as shown in item 19, contained quite an amount of ash and other refuse. The coal was soft and a great deal of it very fine, and it crumbled to pieces under very slight pressure. Altogether I should say that its quality was considerably below the average of the coal that is mined at George's Creek, western Maryland, the point from which the coal in question was obtained.

Nevertheless the evaporative efficiency of the plant is very fair. Item 31 shows that the evaporation per pound of coal varied from 7.04 to 10.1 pounds of water under actual conditions, and the equivalent evaporation from and at 212° F. varied from 8.29 to 12 pounds of water per pound of combustible as stated in item 33. The fluctuation in these values is due partly to the fact that some of the boilers are more efficient than others, but the most potent factor in the reduction of the economy is the inefficient loading of the plant.

During the greater portion of the time the boilers were not developing 60 per cent. of their capacity based upon 11.5 square feet of heating surface in the tubes per horse-power, and at

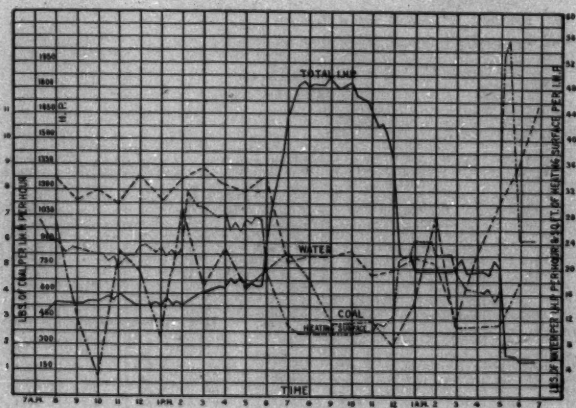


FIG. 3.—Pratt Street Station, Economy Record, Aug. 31, Sept. 1, 1895.

other times they were not developing half of their capacity. This statement is equivalent to saying that during a considerable portion of the test a good share of the heat of the furnaces was used up in heating the iron frame work and the walls, instead of being utilized in evaporating water into steam.

To illustrate this condition of affairs more clearly, an economy record has been plotted in Figs 3 and 4. These plates show the relative amount of coal, water and square feet of heating surface in the boilers per indicated horse-power. The "heating surface" curves are the ones to which I would call your attention at present. It will be noticed that up to 2 o'clock in the afternoon of

each day there was an average of over 22 square feet of heating surface in the part of boiler plant in active operation to each indicated horse-power developed by the engines. Between two o'clock and six o'clock, the ratio of heating surface to horse-power is increased to 29, and it is not until 7 P. M. that the ratio falls within the limits of economic operation. Between 7 P. M. and midnight on August 31, the boiler plant developed within 20 per cent. of its true horse-power and as a result the economic evaporation went up to a very good value—9.3 pounds of water per pound of combustible. The same result was apparent during the same period on the night of September 7, and although the

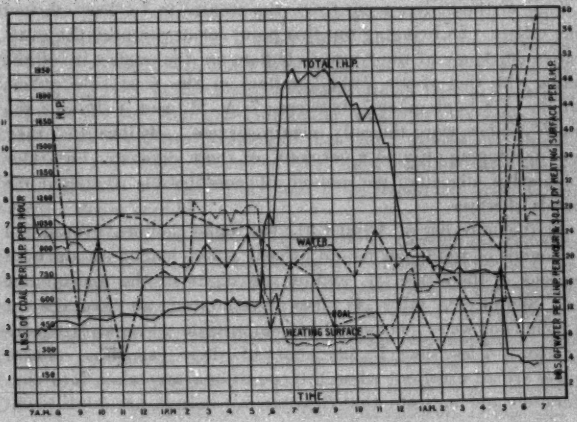


FIG. 4.—Pratt Street Station, Economy Record, Sept. 7 and 8, 1895.

evaporative efficiency is not apparently as high, it is well above the average evaporative efficiency of the plant for the whole 24 hours. In considering the results of the partial tests it must be borne in mind that they are not absolute. They are based on the assumption that the water and coal were supplied to the boilers in just the proportion necessary to meet the requirements of the load, but of course it was not possible to do this with absolute accuracy. For instance, the curves in Figs. 1 and 2 show that proportionally more coal and less water were supplied to the boilers on August 31 between midnight and 7 A. M., than during

the same hours on September 7, and the effect of this is to reduce the apparent evaporative efficiency of the boilers on September 7, during the periods covered by the partial reports. None of the partial reports take in the early morning hours.

It is noticeable, however, that the efficiency of the boilers is relatively lower during the periods when the average heating surface per I. H. P. is high than at other times. Between 3 P. M. and 1 A. M., for instance, when there is an average of about 16 square feet of heating surface per I. H. P., the boilers only develop 64 per cent. of their capacity and only evaporate an average of 8.19 pounds of water per pound of combustible (see item 33).

Some of the boilers seem from the results to be less efficient than others. In bringing out this point let us compare the evaporative efficiency of the "new" boilers on the east side of the station with that of the "old" boilers on the west side of the station. On September 7, between 7 A. M. and 1 P. M., the "new" boilers were the only ones in service. By item 45.5 they were developing only 44.8 per cent. of their capacity, but their evaporative efficiency per pound of combustible averaged 6.8 pounds of water.

On the morning of August 31, the same boilers evaporated 9.9 pounds of water per pound of coal when loaded to only 53 per cent. of their capacity, and on the night of the special test (see column 9, table 4) they evaporated an average of 12 pounds of water per pound of combustible when working under a load of less than 75 per cent. of their capacity. These figures are all excellent when the conditions are taken into consideration and indicate that the "new" boilers are highly efficient.

Now, although the old boilers were never operated alone, and we have no records showing their absolute evaporative efficiency we can nevertheless judge of their economy very accurately by noting the effect they have upon the evaporative efficiency of the plant when they are operated in connection with the "new" boilers. For instance, between 3 P. M. and 1 A. M. of each of the 24-hour tests the whole plant was loaded to 64 per cent. of its capacity and it evaporated an average of only 8.2 pounds of water per pound of coal. This figure does not begin to equal the evaporation of the "new" boilers when operated alone, at a less percentage of their capacity. Again the whole plant even when

operated at an average of 81 per cent. of its capacity between 7 P. M. and midnight did not reach the evaporative efficiency that the "new" boilers developed on the morning of Aug. 31, and did not come within 17 per cent. of the evaporative efficiency of the "new" boilers during the special test, although they were more efficiently loaded.

It seems that sufficient evidence has been produced to establish the assertions that the evaporative efficiency of the "new" boilers is good, and that the evaporative efficiency of the whole plant is only fair. This means that there is a disturbing element present somewhere and the general indications are that the defect lies in the old boilers. It would not be surprising to find that the "old" boilers will not evaporate over 6.5 or 7 pounds of water per pound of coal even under the most favorable conditions of loading and when fired with the best quality of coal. During my stay at the plant, I several times had my attention called to the fact that great difficulty was often experienced in keeping up the steam pressure in the "old" boilers, and this was expressly noticeable whenever the "new" boilers were cut out for any reason and the "old" had to be depended upon to furnish the steam supply.

The quality of the steam evaporated by the boilers remained fairly constant. At no time during any of the tests however was the slightest trace of superheating discernible. The smallest percentage of moisture recorded is that at 2 P. M. on Sept. 7, when only .3 of one per cent. of moisture was apparent. The greatest percentage of moisture was recorded at 6 A. M. on Sept. 7, when there was 1.24 per cent. of moisture in the steam. On the whole however, the percentage of moisture is low and it is also very uniform for all loads. It may be well to note that the pipe condensation, as determined by collecting and weighing all the drainage water from the separators and steam traps, proved to be .505 of one per cent. of the total water actually evaporated on Aug. 31; .31 of one per cent. of the water actually evaporated on Sept. 7; and nearly .5 of one per cent. of the water actually evaporated during the special test. These figures represent to a large extent the proportion of the entrained water and water of condensation that was extracted from the steam by the separators, as most of the drainage water was taken from them, and it is safe to say that the separators extract fully 70 per cent. of the moisture contained in the steam, from the

steam. This leaves the steam practically dry when it passes the separators. The average of about 2 per cent. of moisture that the steam in the steam pipe of engine No. 1, was found to contain on the night of the special test, was largely due to there being no separator between the engine and the boilers.

The greatest amount of coal is fired to the boilers on both days between 7 and 8 o'clock in the evening when the fires are being built up for the heavy night load. At this time the coal is supplied at the rate of 7500 pounds per hour. On this account exception may be taken to the evaporative efficiencies determined for the boilers between 7 P. M. and midnight on the score that the proportion of the coal fired within this time is in excess of the normal requirements of the boilers. In answer to this I will call attention to the fact that the fires were about burnt out at midnight, as the coal curves of Fig. 1 and 2 both show that the rate of firing had to be increased immediately after midnight.

The rate of combustion per square foot of grate surface conforms to the practice common with boilers of this class. The maximum rate maintained was 13.8 pounds on September 7, during the heavy night run, and the lowest appears to have been on the morning of August 31, when it amounted to 9.5 pounds. The maximum efficiency of the boilers will probably be attained when the combustion averages between 12 and 13 pounds of coal per square foot of grate surface per hour. The rate of combustion per square foot of heating surface is also rather low and plainly indicates that even during the heaviest loads the limit of economy in this respect was not reached by 20 or 25 per cent.

Finally, the results of the tests demonstrate the fact that the daily economy of the station would be greatly improved if greater care were exercised in the adjustment of the capacity of the boilers in service to the load. Boilers Nos. 6, 7, 8 and 9 will easily and economically generate an actual indicated horse-power for every eight square feet of their heating surface. This will make the capacity of each boiler, relatively to the demands of the engines, equal to 350 H. P., and will represent a total capacity equivalent to 1,400 I. H. P. If the requirements of the load had been economically met, only boilers 6 and 7 would have been operated between 7 A. M. and 6 P. M. on the days of the tests; between 6 and 7, boilers Nos. 3, 4, 5, 8 and 9 would have been cut in; between 11:30 P. M. and 12:30 A. M., boilers 3, 4 and

5 would have been cut out, and between 12:30 A. M. and 1 A. M. boilers 6 and 7 would have been cut out. This would have left boilers 8 and 9 in service to carry the load until 5 A. M. when one of them could have been cut out and the other left to carry the Sunday load, which is always light. Such a boiler schedule would have entirely eliminated the necessity of operating the entire plant and would have resulted in an average economic evaporation of between 11 and 12 pounds of water per pound of coal.

This would mean a saving of between 25 and 31 per cent. of the coal fired into the boilers. These figures are based on the assumption that boilers 1, 2, 3, 4 and 5 will evaporate the water for one indicated horse-power per hour from each 11.5 square feet of their heating surface, and that boilers 6, 7, 8 and 9 will evaporate the water for an indicated horse-power per hour from each eight square feet of its heating surface. Under these conditions the boilers would be economically loaded and capable of developing their best economy in consequence.

If we compare the actual economy of the station boiler plant with the results that have recently been published by the *National Electric Light Association*, we find that the actual evaporation per pound of coal is above the average, that the actual evaporation per pound of combustible is about equal to the average, and that the evaporation from and at 212 degrees, per pound of combustible, is a little below the average of the figures published for these quantities.

This simply means that there is room for improvement, although it must be admitted that the coal used in the stations exceeding the economy of the Pratt Street Station seems to be of better quality.

During the heavy loads the economy of the boiler plant was above the average of tests reported, and during the "special" test it exceeded everything reported by the *National Electric Light Association*.

Notes on the Arc Lighting Machinery.

The special test of Engine No. 1 and Dynamos No. 7 to No. 18 :—Three tests were made upon engine No. 1 and the arc light machinery driven by it. Two of these, the first and the last, were made in connection with the general station tests of Aug. 31st and Sept. 2nd, but the second was for the special purpose of determining the evaporative efficiency of the newer part of

the boiler plant; namely, boilers Nos. 6, 7, 8, and 9, and the steam consumption per indicated horse power per hour of the engine in question.

For the special test it was decided to use boilers, Nos. 6, 7, and 8, thus providing a total boiler capacity of 750 H. P. to meet the requirements of the load on the engine, which frequently amounted to over 700 H. P.

The stop valves leading to engines Nos. 2, 3, 5, and 8 were securely closed. Suitable small tanks were provided to receive the water that acccumulated in the separator in the centre of the station and to catch the condensed steam, when it was removed from the various points at which it collected. The total amount of pipe condensation for the eleven hours' run was 1168.9 pounds or 0.5 of one per cent. of all the water evaporated in the boilers.

The report of the trial of the boilers is given in table 4, column 9. The performance of the boilers was very creditable. The evaporation of 12 pounds of water per pound of combustible from and at 212° Fah. is far above the average evaporation obtained in the central stations throughout the country and will compare favorably with the best tests yet reported upon water tube boilers. The average horse-power developed by the boilers during the test was 25.75 per cent. below the rating of the boilers, allowing 11.5 sq. ft. of heating surface in the tubes per horse-power. The evaporation of 12 pounds of water would therefore probably have been exceeded had the load upon the boilers been heavier, as they are designed to admit of a considerable overload.

The quality of the steam evaporated was determined by a throttling calorimeter placed in the side of the east main between boilers No. 7 and No. 9. The results showed that at no time was there more than 1.07 per cent. of moisture in the steam and that at times this figure was reduced to 0.7 of one per cent.

The pyrometer test of the flue gases showed that their temperature at the base of the stack, where the pyrometer was placed, was about the same as the temperature of the steam generated in the boilers. This indicates that little of the furnace heat is wasted, and speaks well for the design of the boiler.

The load on the engine was practically constant at 700 H. P. during the earlier part of the evening, and was reduced to a value of about 480 H. P. during the latter part.

The average I. H. P. for the whole test is 553.82 H. P. and the average E. H. P. is 382.6 H. P. The ratio of these would give an apparent efficiency of conversion of 69.04 per cent. This is the usual method of determining such efficiencies and it gives a very gratifying result, when we compare it with similar results of tests on lighting plants of this type that have been published. The real average efficiency, however, is the average of the ordinates of the efficiency curve which is 66.7 per cent. This is the lowest value obtained on either of the three tests made upon this engine, a fact that is probably due to the load having been somewhat lighter than during the other tests.

One object of this test, however, was to determine the actual water consumption of the engine. The values were obtained by dividing the pounds of water delivered to the boilers during each hour by the average I. H. P. for the corresponding hour. The amount varies from 26.9 to 38.3 pounds, the average being 32.96 pounds of water per I. H. P. per hour. This value is extremely high for an engine of this type. The theoretical value computed from the indicator cards gives an average of about 18 pounds of water per I. H. P. as the water consumption. If we add to this the percentage for internal condensation that practical experience has shown is necessary, we find that the engine ought not to require over 23 pounds of water per I. H. P. and everything above this value is in excess of the limit of even fair economy. This excessive water rate is partly due to the low ratio of expansion employed, but chiefly to leakage of steam past the pistons of the engine.

An examination was made of the cylinders, and the valves and pistons were tested for leakage. The inside of the high pressure cylinder was found to be quite a good deal cut all round, especially on the left side parallel to the axis of the cylinder. When steam was turned on it blew past the piston uniformly all round, except in one place on the right side where the leakage was somewhat greater. The steam chest cover was removed and the valve examined. The design of the valve is such that it delivers steam from both sides. It seemed to be tight on its seats but the steam leaked through a joint in its center into the receiver.

The steam chest cover and the high pressure cylinder cover were replaced and the low pressure cylinder head removed. The bottom and the sides of the low pressure cylinder half way up,

showed a good deal of wear, the surface of the cylinder being quite rough. With the crank of the high pressure piston on a dead center, steam was turned on. It leaked into the receiver, and the pressure in the receiver rose to 15 pounds gauge pressure in one minute, although steam was blowing past the low pressure piston freely all the time.

Fifteen pounds pressure in the low pressure cylinder should have been sufficient to blow the piston rings out to the sides of the cylinder and stop the leakage past the piston had the piston, its fittings and the sides of the cylinder been in good condition. There can be no reasonable doubt but that there was leakage of steam past the pistons of this engine during its operation. This fact can also be detected from the indicator cards. The results of the calorimeter tests that were made of the quality of the steam in the steam pipe and the receiver during the run of Sept. 1st and 2d, show that at 10 P. M. the steam entering the high pressure cylinder contained 1.86 per cent. of moisture, but that when it was discharged into the receiver it *contained only* 0.79 *per cent. of moisture.* About this same quality was determined for the steam in the receiver during the entire time of the heavy load, but whenever the load became lighter (500 H. P. or less), so that the steam expanded to about twice its initial volume in the high pressure cylinder, between 7 and 13 per cent. of moisture became apparent in the steam in the receiver. In other words the steam was wet when discharged from the high pressure cylinder. These results were obtained with a throttling calorimeter on the steam pipe, and a throttling and a separating calorimeter on the receiver, and have an important bearing upon the water consumption of the engine.

So far nothing has been said regarding the mechanical efficiency of engine No. 1.

The engine is directly connected to a very large line of shafting extending along the east side of the station a distance of 70 feet. This line shaft is supported on eight evenly spaced pedestal bearings, and is equipped with 12 friction clutch pulleys to which the dynamos are belted.

The average indicated friction horse power of the engine amounted to 54.31 H. P. with the clutches thrown on, and to practically the same (54.1 H. P.) with the clutches thrown off. These are the lowest values of the friction load recorded, and it is a noticeable fact that the friction of the clutch pulleys is about

the same as the friction of the armatures and belts of the dynamos. It would therefore seem that although the use of friction clutches reduces the wear on the dynamos when they are out of service, they do not reduce the friction load.

The friction cards taken on Aug. 31st indicated that the power absorbed in the friction of this shafting is often in excess of the

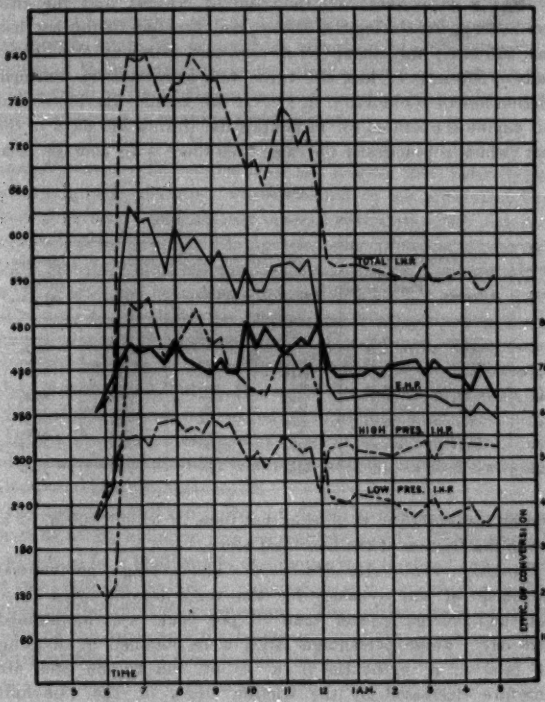


FIG. 5.—Engine No. 1. Dynamos Nos. 7 to 18, Sept. 7 and 8, 1895.

figures just noted. In fact, the results of the tests made on Sept. 1st and 7th show a difference of over 225 H. P. at times between the indicated horse power of the engine and the total electrical horse-power developed. If we allow 40 H. P. of this amount for

the friction of the engine alone, and the same amount for the friction of all the loaded dynamos, 145 H. P. or 18 per cent. of the power developed by the engine still remains unaccounted for, and since an ample allowance has been made for the engine and dynamos, it may be attributed to the friction of the shafting. This excessive friction only occurs during the heavy loads of 700 I. H. P. or over. On the night of August 31st the friction horse-power during the heavy load averages somewhat less than 225 H. P.; only about 150 H. P. in fact. During the lighter loads of 500 H. P. or less, the three tests show a very uniform friction loss of about 145 I. H. P. If we assume therefore that this engine is operated for 11 hours a day during 313 days in the year (which is practically the case) then there is an average total

TABLE 5.

DATA FROM TESTS OF ARC MACHINES.

No. of arc dynamo.	Resistance.		Average Voltage Developed.			Average electrical efficiency. per cent.
	Armature.	Regulator and series field.	Aug. 31.	Sept. 1.	Sept. 7.	
7	13.63	30.81	3773	3728	3819	90.22
8	13.2	32.42			4097	90.42
9	13.05	31.96	2957	3110	3368	88.01
10	13.47	30.5	2545	3387	3330	88.04
11		30.1	2810	3801	3784	
12	12.43	29.7	3849	3970	3867	89.89
13	13.1	30.55	3606	3667	3896	89.72
14	13.2	30.59	3344	3706	3142	88.80
15	13.05	30.8	3622	3631	3858	89.85
16	13.11	31.09	3450	3320	3690	89.22
17	12.5	29.01	3240	3440	3799	89.83
18	12.51	30.4	3452	3505	3644	89.62

friction loss of 175 H. P., during that time, of which 100 H. P. is due to the friction of the line shaft alone.

Economy of the Arc Machines.—The average commercial efficiencies of the dynamos for the three tests recorded show that an average greater than 76 per cent. was maintained each day. These percentage ratios were obtained by dividing the total E. H. P. by the D. H. P. of the engine and are therefore decreased by the friction losses of the line-shaft and of the dynamo belts. The true efficiencies of the dynamos are therefore higher than these figures would indicate, and although it was impossible to make any exact determination, the following condensations lead us to a very close approximation. In table 5 will be found a statement of the average electrical efficiencies of the dynamos. These are determined from the

measurements that were made of the resistances of the armature and field windings of the machines and the average electrical horse-power developed by each machine during the three tests. The average of these efficiencies is 89.4 per cent., and if 5 per cent. is allowed for the remaining losses, we get 84 91 per cent. as the average commercial efficiency of the dynamos.

If we assume that the average yearly load upon the engine is 606 H. P., 68 per cent. of it is delivered as electrical energy for distribution, about six per cent. is absorbed in overcoming the friction of the engine, 10 per cent. is dissipated as heat due to the electrical and mechanical losses of the dynamos and 16 per cent. is absorbed in running the line-shaft.

Engine No 2, *Arc Machines Nos.* 4, 5 *and* 6, *and the Wenstrom Dynamo.*—The engine is of the Russell four valve type, and as originally designed was regulated by an automatic fly-wheel governor. As, however, the fly-wheel governor did not work satisfactorily under 125 pounds boiler pressure, it was removed and the engine equipped with a throttling governor after the valve gear had been somewhat modified.

Previous to the tests the engine was thoroughly examined. The cylinder was in good condition. It was found, while measuring the clearance of the cylinder heads, that the piston and valves leaked water, but on the other hand they proved to be tight to steam when it was turned on to its full force.

During the tests a steam gauge was placed on the steam chest and a throttling calorimeter connected near it. These were the only special arrangements made.

The distribution of the power developed by the engine, between the ends of its cylinder was very nearly equal. There seemed however, to be a tendency to over-balance on the head end. But the most striking feature in connection with this engine is the action of the throttling governor. The initial steam pressure shown by the cards and the boiler pressure are graphically exhibited in Fig. 6. It is noticeable that although the boiler pressure is practically constant at something over 125 pounds gauge pressure, the steam chest pressure remains at about 35 pounds all during the day and falls as low as 20 pounds whenever the I. H. P. of the engine falls below 50 H. P. Even when the engine is developing 160 I. H. P. the steam chest pressure does not average above 50 pounds by gauge. This excessive throttling of the steam to from .4 to .16 of its initial pressure is very wasteful of

the heat energy contained in the steam and results in a high water consumption per I. H. P. per hour.

The calorimeter tests made upon the quality of the steam in

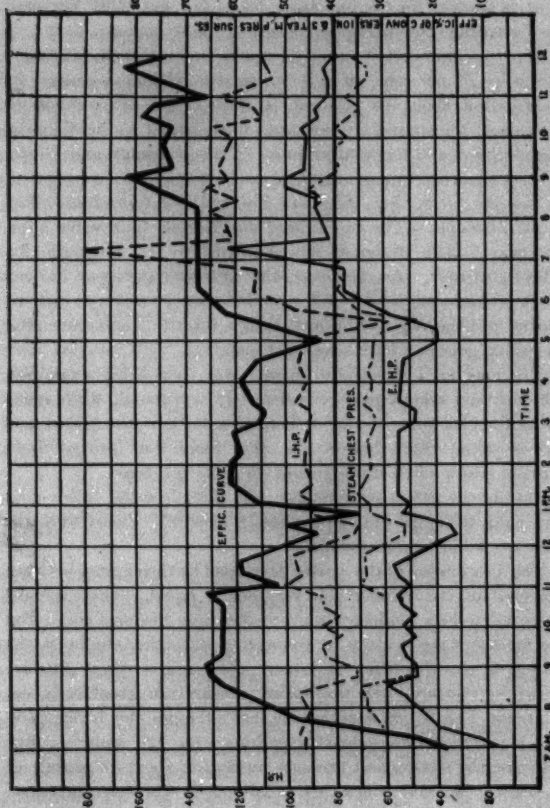


FIG. 6.—Engine No. 2. Dynamos 4, 5, 6 and W. Sept. 7 and 8, 1895.

the steam pipe, and in the steam chest, showed that as high as 24.4 degrees superheat is developed in steam initially containing 1.27 per cent. of entrained water.

In the calculations that have been made of the actual water consumption of the engine per indicated horse-power per hour, the theoretical results have been assumed to be correct, owing to the superheated condition of the steam entering the cylinder, and no allowance is made for cylinder condensation. Even under these conditions, the water consumption is high; during the light loads of about 50 H. P. it amounts to 49 pounds of water and during the heavy loads of 158 H. P. it runs as high as 30 pounds of water. Had the same correction for condensation been made here as in the case of the other simple engines the above figures would have been 64 and 35 pounds of water respectively.

The difference between the I. H. P. and the E. H. P. during the two days tests seem to average about 35 H. P. *for all loads* above 80 I. H. P. of the engine. This shows at once the advantage to be gained by keeping the engine well loaded.

To secure high efficiency it is by all means necessary to operate arc dynamos as near full load as possible, their efficiency at half load being little better than 70 per cent. and at one quarter load only about 50 per cent. The bearing of this fact upon the case in hand becomes evident when it is known that during the day all the dynamos operated by this engine are loaded to less than one-half their normal capacity.

Engine No. 3 and Arc Dynamos Nos. 1, 2 and 3:—Upon examination, the equipment was found to be in good order. The engine proved to be sound in every particular.

In view of the fact that this engine, one of the oldest in the station, is in such good condition, and that it is operated under low pressure superheated steam, the temperature of which is almost as high as the temperature of the high pressure steam in the steam pipe, it does not seem probable that the excessive cutting in the cylinders of some of the engines can be due either to grit brought over in the steam from the boilers, or to the temperature of the steam interfering in the least with the cylinder lubrication. It would appear rather to be due to the fact that the engines referred to have not been properly designed for use with such high pressure steam, and that in consequence the piston rings bear upon the cylinders with such force that trouble ensues. Frequently the piston rings break, and then the weak spots in a cylinder suffer severely.

Like engine No. 2, the engine under discussion is regulated by means of a throttling governor, and all of the peculiarities that

were found to be characteristic of engine No. 2 are present in engine No. 3, only in an intensified degree. See Fig. 7.

During the light loads of 40 I. H. P. the water consumption

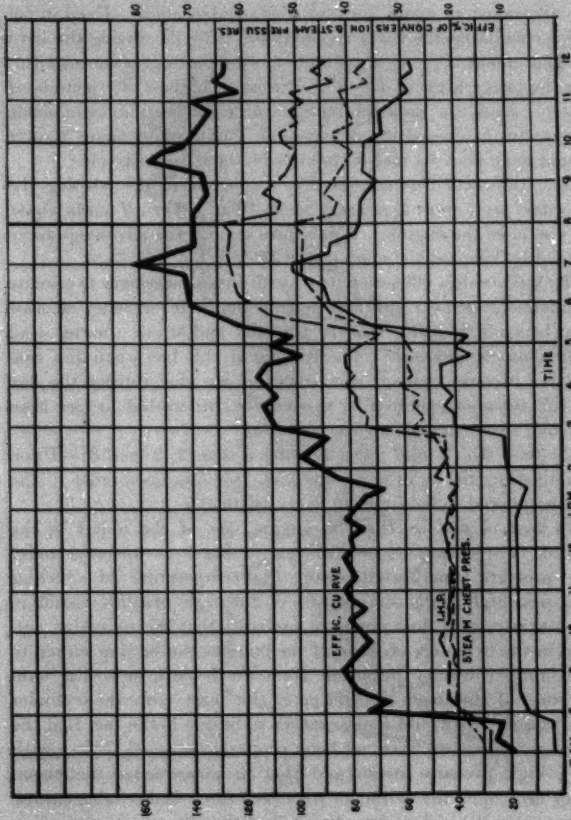


FIG 7.—Engine No. 3. Dynamos Nos. 1, 2 and 3. Sept. 7 and 8, 1895.

accounted for by the cards averages about 55 pounds. For the heavier loads requiring 125 I. H. P. or over, the water consumption by card falls off to 30 pounds. At these loads however it is

doubtful if the superheating is as effective in reducing cylinder condensation as at the lighter loads, both because the ratio of expansion by pressures is increased, and because the throttling of the steam during the heavier loads is very much less. Probably for these loads 25 per cent. should be added to the theoretical value for condensation.

The value of 42.59 pounds of water corresponds to the theoretical value obtained from cards showing about 70 I. H. P.; and, as during these loads the stem is throttled from 130 pounds to 25 pounds by gauge, the theoretical value is assumed to be equal to the real value.

The tests of the Arc Lighting Plant:—Being familiar with the general results of the tests made upon the arc lighting equipments considered independently of one another, it remains to give an account of the economic working of this machinery when considered in the light of a single plant. To this end the results of tests of the three separate equipments have been summed up.

On Aug. 31st the I. H. P. developed by the engines did not amount to over 150 H. P. up to six o'clock in the evening, it then rose to about 975 H. P. as the night load of commercial arc lamps and street lights came on. The total arc load remained about constant until twelve o'clock at night, when engines 1 and 2 were shut down and the commercial circuits opened. After this time the load was carried by No. 1 engine, and it remained about constant at 475 H. P. until the early morning. The efficiency of conversion averages about 61 per cent. between 7 A. M. and 6 P. M. and 12 P. M. and 5 A. M., but between 7 and 11:30 P. M. it averages not far from 77 per cent.

	Aug. 31.	Sept. 7.
The maximum I. H. P. recorded is	999	1146
The maximum E. H. P. recorded is	760	847
The average I. H. P. recorded is	404.8	434.8
The average E. H. P. recorded is	284.2	296.7
The average efficiency of conversion is	66.2%	61.9%

The arc lighting plant record for Sept. 7 and 8, is graphically represented in Fig. 13. The load on Sept. 7, did not average as high during the day as it did during the first test, but at night it made up for it very handsomely. The load increased on engines 2 and 3 about 5:30 P. M. and when engine No. 1 was started at six o'clock it immediately rose to a high value.

Eleven hundred and forty-six H. P. is just 250 H. P. in excess of the rated capacity of the engines, and if it had been evenly

distributed would have amounted to an overload of 27 per cent. The maximum electrical load was 7.6 per cent. below the rated capacity of the electrical machinery. On account of the load being light during the day, the average efficiency up to six o'clock .P M. is but little better than 51 per cent. and even during the heavy load between 6:30 P. M. and midnight the efficiency averages 4 per cent. lower than it did on the night of Aug. 31. During the morning run, however, when No. 1 engine was operated alone under an average load about 100 H. P. heavier than the load was during the morning of Sept. 1 the efficiency improved upon the first test about six per cent.

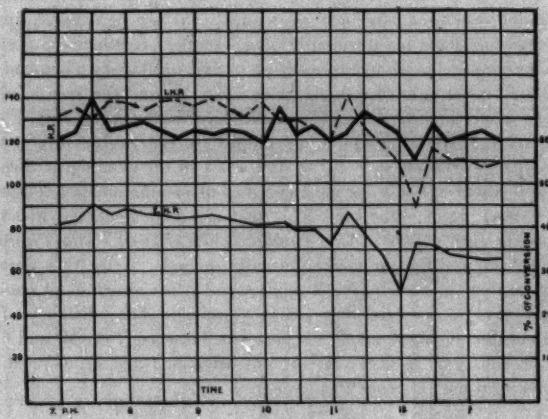


FIG. 8.—Engine No. 4, Dynamo E. Sept. 7 and 8, 1895.

Now the variations in the total efficiency of the arc plant on the two days are simply due to the fact that engines No. 2 and No. 3 were not loaded as heavily on Sept. 7 as they were on Aug. 31, and consequently although the load on the entire plant was heavier on the second day, the inefficient operation of a part of the plant entirely counteracted the good effect that usually comes with good loads.

If we calculate the apparent efficiency and take the ratio of the average I. H. P's. to the average E. H. P's. we obtain a very gratifying but a very deceptive result.

The apparent efficiency for the run of Aug. 31 is 70 per cent., and the apparent efficiency for the run of Sept. 7 is 68 per cent. A glance at the efficiency curve on Fig. 13 will immediately show that these results are of little value as an aid to gauging the *average hourly efficiency* of the plant. The "apparent efficiency" is however, of great value in determining the daily commercial economy of the machinery, since it equals the ratio of the average hourly product of the indicated horse power and the efficiency of conversion, to the average indicated horse power.

Had the entire day load been carried by engine No. 2, and had engine No. 3 not have been put in service until six o'clock (on either day,) No. 3 would have been just nicely loaded, and would have developed an efficiency of 75 per cent. or over. This would have had the result of making the all day efficiency of the plant about 73 per cent. on Aug. 31st and about 74 per cent. on Sept. 7th, instead of 66 per cent. and 61 per cent. respectively. When we remember that the steam economy of the plant during the day run would have been increased in even a greater proportion, the real increase in economy to be gained by such an arrangement becomes apparent.

Notes on the Incandescent Lighting Machinery.

Engine No. 4 and Alternator E.—This set consists of a simple horizontal high-speed Buckeye engine that is belted to a 16-pole Slattery alternator.

A very important point brought out by the tests on engine No. 4, is the necessity of having the valve of an engine properly adjusted. Without exception the cards from this engine showed that the admission of steam into the cylinder was far from free.

Between admission and cut-off the steam pressure was reduced about 40 per cent., whereas the corresponding decrease in engine No. 6 was practically negligible. As the steam pipe connections to these engines are of the same dimensions, with the advantage on the part of engine No. 4 of being nearer the boilers on the same steam main, the throttling of the steam must occur in the valve of engine No. 4. The effect of this throttling is to increase the apparent water consumption of engine No. 4, as shown by the cards, 14.7 per cent. above that shown by the cards of engine No. 6.

Engine No. 5 and Alternator F.—The engine runs very smoothly and regulates well, and the dynamo is so well designed and compounded that it needs practically no attention.

The only thing to mar the perfect adjustment of the engine was the fact that the ratios of expansion and the I. H P. developed during the test were not equalized between the cylinders. The ratio of expansion in the high pressure cylinder was about twice as great as the ratio in the low pressure cylinder. The power indicated in the high pressure cylinder was also much greater than in the low pressure cylinder.

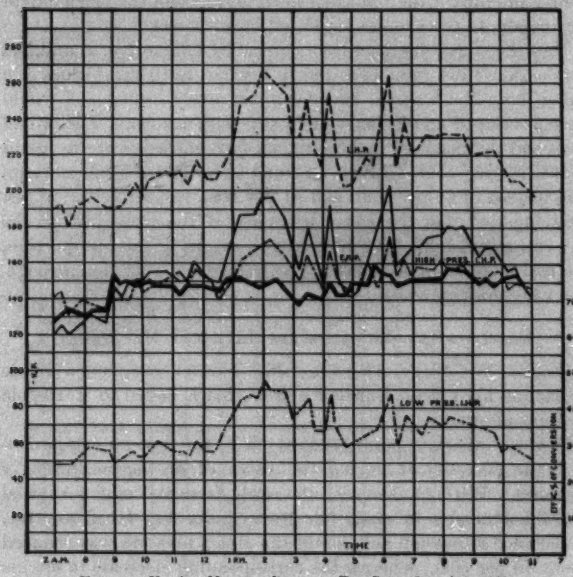


FIG. 9.—Engine No. 5. Dynamo F. Sept. 7 and 8, 1895.

During the tests, the load on the equipment required an average of 216 I. H. P. and there were no fluctuations of long duration on either side of this mean value of over 12 per cent. (see Fig. 9). If, therefore, the valves had been properly set for 216 I. H. P., there would have been a gain of several per cent. in the water consumption economy of the engine.

On the whole the performance of the engine was very creditable. It did not require much over 22 pounds of steam per I. H. P. per hour and the steam was expanded over nine times before being exhausted.

From the measurements that were made of the resistances of the various windings it would appear that the full load electrical efficiency of this dynamo is about 95.5 per cent., including the exciter and the exciter circuit. At full load the alternator develops 201 E. H. P.

The efficiency of the equipment on the basis of a full load of 200 E. H. P. on the dynamo, is 86.5 per cent. for the engine efficiency, 89.5 per cent. for the dynamo efficiency, and 77.3 as the efficiency of conversion.

Engine No. 6 and Alternator D.—The engine and dynamo that form this equipment are counterparts of engine No. 4 and dynamo E.

The dynamo was in good mechanical running order and developed no weak points during the tests.

The determinations that were made of the "actual" water consumption of the engine from representative indicator cards, ranged between 21.39 and 26.21 pounds of initially dry and saturated steam per indicated horse-power per hour, and after a careful review of the results and the conditions governing the test, it has been thought safe to assume that the engine did not consume on an average more than 22.6 pounds of steam per indicated horse-power per hour. The steam was expanded over 4.5 times, both by pressures and volumes.

The commercial efficiency of this set seems to be better than that of engine No. 4 and dynamo "E." In fact there is a difference of about four per cent. for all loads.

The efficiency of the engine is about 84 per cent. when the dynamo is fully loaded, and the efficiency of the dynamo is 88.2. These deductions are based upon the assumption that the full load efficiency of conversion of the equipment under the conditions of a constant load would be 73 per cent.

Engine No. 7 and Alternators B and C.—The engine is of the high speed cross-compound type manufactured by the Ball & Wood Company. Upon examination it proved to be in very good condition.

The records of the power developed in the cylinders indicate that the division of the work between the ends of either of the cylinders considered by itself was very nearly equal, but that the division of the work between the two cylinders was very unequal. During light loads of 150 I. H. P., 73 per cent. of the power of the engine was developed in the high

pressure cylinder, and during the heavy loads of about 240 I. H. P. 60 per cent. of the total power was developed in the high pressure cylinder. Following this same proportion it appears that the power developed in the cylinders would be equal when the engine is indicating 310 H. P.

With the engine loaded to 310 H. P. it is probable that the water consumption shown by the cards and the ratios of expansion of the steam in the two cylinders would be more nearly equal, since in this event the receiver pressure would increase and compression in the high pressure cylinder decrease.

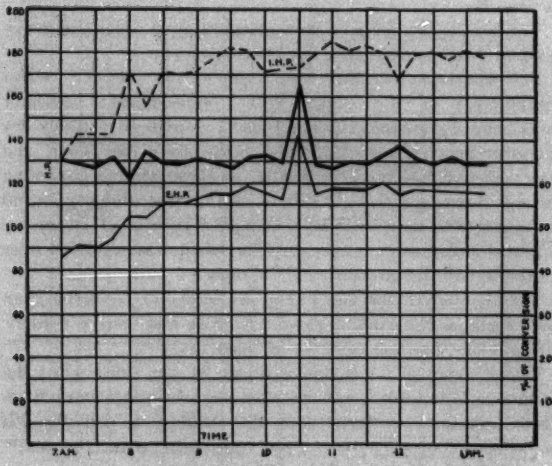


FIG. 10.—Engine No. 6. Dynamo D. Sept. 7 and 8, 1895.

At the time of making the tests, however, the valve setting was not at all adapted to the load. Cut-off in the low pressure cylinder and compression in the high pressure cylinder occurred much too late, and in consequence the receiver pressure is low, and the low pressure piston compresses the steam to a pressure between 10 and 15 pounds higher than the receiver pressure.

These things cause the water consumption shown by the cards to be greater in the low than in the high pressure cylinder. As, however, by far the *greater portion of the work* performed by

the engine is done in the *high pressure cylinder*, and as the ratio of expansion in this cylinder is much higher and, therefore, the cylinder condensation proportionally greater than in the low pressure cylinder, the "actual" water consumption determined from the high pressure cylinder cards is considered to be a fairly accurate determination of the real water consumption per I. H. P. per hour of the engine.

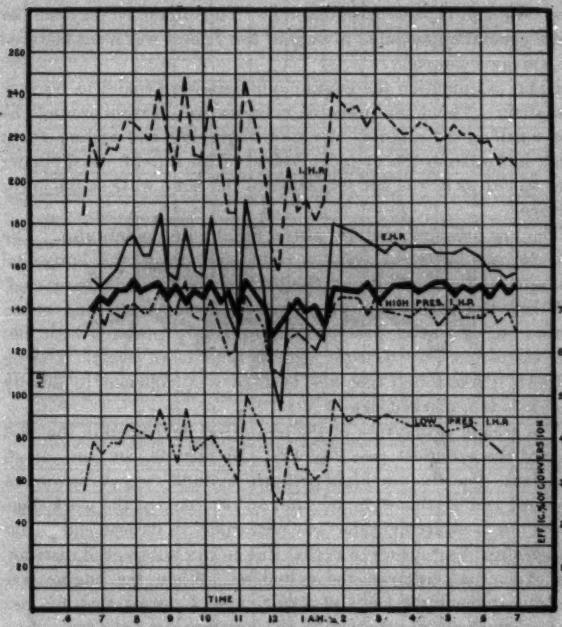


FIG. 11.—Engine No. 7. Dynamos B and C. Sept. 7 and 8, 1895.

Based upon these assumptions, the engine showed an economy of 21.5 pounds of water per I. H. P. per hour during the tests.

The final results of the tests (see Fig. 11.) show that the efficiency of this equipment, in spite of the fact that it contains *two* belted units, is very good. During the run of Aug. 31, the average efficiency of conversion was only 63 per cent. but this

was because the load on the engine was very light during a considerable portion of the time, so that between 4 P. M. and 7 P. M. the efficiency of conversion averaged but little over 55 per cent. Later in the night when the load rose to 240 H. P. the efficiency also improved and averaged above 70 per cent. The importance of keeping units well loaded cannot be too strongly emphasized.

Engine No. 8 and Alternator A.—Alternator A is of the same size and type as Alternator F. The engine is very similar in its general appearance to engine No. 5, and was manufactured by the same company.

Upon examination the engine cylinders were found to be very badly cut. The high pressure cylinder was scarred around the lower half in the middle, the scars beginning and ending about three inches from the cylinder heads. The top of the cylinder was smooth as it was not subjected to the same wear as the lower surface.

The low pressure cylinder piston fitted quite loosely also. The cylinder was badly cut on the right side below the horizontal diameter and extending past the bottom line two or three inches.

When the crank was placed on its dead centers and steam turned on, it leaked past the high pressure piston a little, but *past the piston valve into the receiver to quite an extent.* During the tests it was found that this leakage was sufficient to modify the cards to a marked degree.

The greater proportion of the power was developed in the head ends of the cylinders (see Fig. 12). In fact 63 per cent. of all the work done in the high pressure cylinder was performed in the head end of that cylinder, and 56 per cent. of the work done in the low pressure cylinder was performed in its head end. But the greatest discrepancy was that due to the unbalanced distribution of the load between the cylinders. When the engine was working under light loads of 160 I. H. P. I found that 62 per cent. of the load was carried by the low pressure cylinder. As a rule, it will be remembered, the high pressure cylinder carries the greater portion of the load during the light loads on an engine, and one would naturally expect the same thing to occur in the present case. As the load increases the condition of things is improved very little, and when the engine is indicating between 260 and 300 H. P., between 60 and 65 per cent. of the power is still developed in the *low pressure cylinder.* This is of course

wrong, and it occurs largely on *account of the leakage* of the steam past the high pressure piston valve into the receiver.

Under these conditions it is not surprising that the calculations for the water consumption of the engine should result in high values being obtained from the low pressure cards. Under the

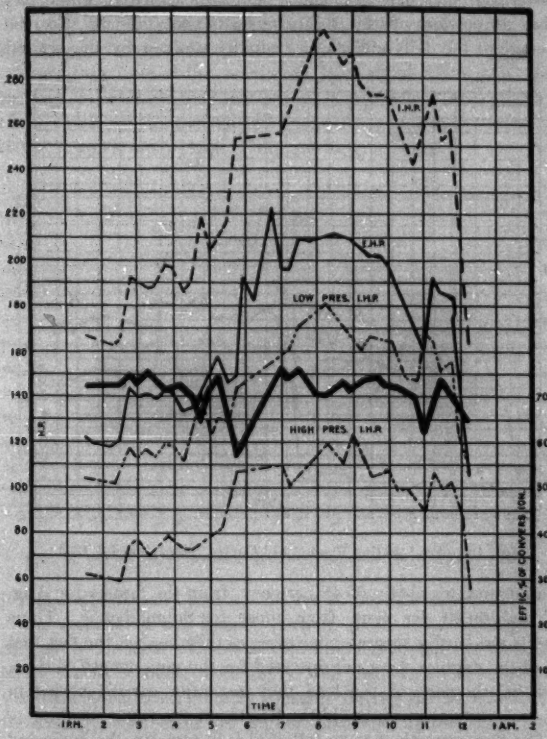


FIG. 12.—Engine No. 8. Dynamo A. Sept. 7 and 8, 1895.

circumstances the value of 29 pounds of water per indicated horse-power per hour, recorded as the average performance of the engine during the tests, should be regarded as a conservative estimate, and it is fortunate if the engine did not make a greater demand upon the boilers than these figures indicate.

The Tests of the Incandescent Lighting Plant.—We now come to a point where it will be interesting to discuss the tests that were made upon the incandescent lighting equipments collectively. It has been shown that it is possible under favorable conditions to operate these equipments at an average efficiency of conversion of 75 per cent., and it is of importance to know just what proportion of this figure was attained. If we take the average of the daily efficiencies actually attained by the several

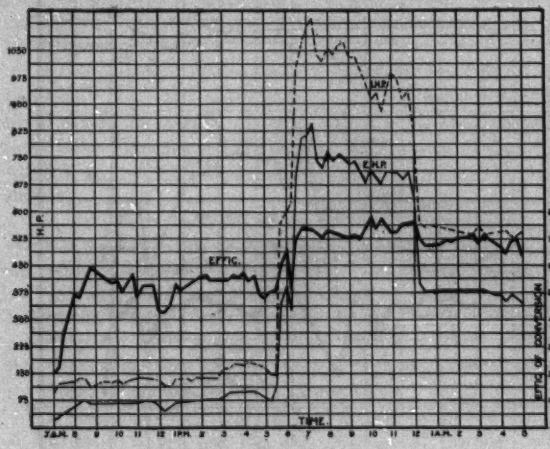


FIG. 13.—Arc Lighting Plant, Load Curves. Sept. 7 and 8, 1895.

equipments, we obtain 66.48 per cent. from the figures for Aug. 31, and 69.30 per cent. from those for September 7. These results are hardly accurate, however, as they neglect the fact that all of the engines were not operated for the same length of time, and that the parts of the load they severally carried varied in amount quite as much as did the lengths of the runs.

The correct method to be followed is to sum up the indicated and the electrical powers developed for the machines for each set of readings, and from these results calculate the hourly efficiency of the incandescent plant. The average of the hourly efficiencies determined in this way will be the real average daily efficiency of conversion of the plant.

This method has been followed in making the determinations of economy that are set forth in Fig. 14.

The load diagrams show that the incandescent load of the station varied about the same on both days, both as regards the time of the variations and their amount. It starts at 7 A. M., at 350 H. P. and rises gradually to 500 H. P. which it reaches about 6 P. M.; between 6 and 8 P. M. it rises rapidly, the crest of the curve being reached about 8:15 P. M.

During the time of the maximum load about 850 I. H. P. and 625 E. H. P. are developed, but this only lasts about an hour and a half, after which it rounds off gradually and finally drops to 250 H. P. about one o'clock in the morning. From this time on

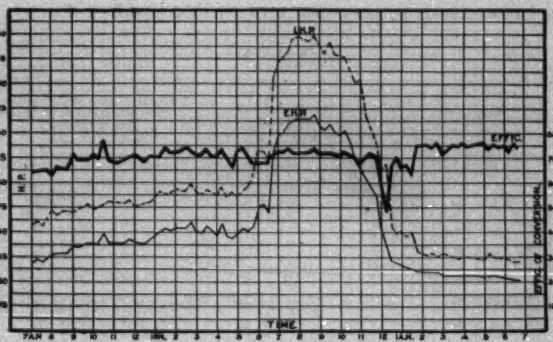


FIG. 14.—Load Curve for Incandescent Machines. Sept. 7 and 8, 1895.

it remains practically constant till the end of the tests.

On account of the greater portion of the load having been carried by the most efficient of the equipments, and the fact that all of the equipments were fairly well loaded, the efficiency of the plant remains very nearly constant during the 24 hours, and the average efficiencies are higher than the figures mentioned earlier in the discussion.

	Aug. 31.	Sept. 7.
The maximum I. H. P. recorded is	876	900
The maximum E. H. P. recorded is	598	661
The average I. H. P. recorded is	458.0	451.0
The average E. H. P recorded is	317.0	332.8
The average efficiency of conversion is	69.0	71.0

The average efficiency maintained on September 7 of 71 per cent. is very creditable when it is remembered that at times the load was divided between four belted equipments. It would seem, however, that even this result could be improved upon if it were possible to distribute the load to the best advantage between the electrical units.

In table 6 is given in tabulated form the results of a careful comparison of the actual electrical load upon the incandescent plant with the actual *rated* capacity of the electrical apparatus supplying the power, and an additional statement is given of the nearest approximation that could be made to the actual load *without going above the rated capacity of any of the electrical units.* The comparisons are expressed in terms of the per cent. that the rated power is above the power actually developed.

TABLE 6.

Time.	Per cent. of the rated capacity of dynamos running above the load.		Per cent. of the rated capacity of the best arrangement of dynamos above the load.	
	August 31.	September 7.	August 31.	September 7.
8:30 A. M.	33	42	7	19
12:30 P. M.	45	10	21	10
4:30 P. M.	60	40	7	12
8:30 P. M.	23	13	5	13
12:30 A. M	25	60	25	30
4:30 A. M	33	22	33	22

In some cases the rated capacity of the machines is 60 per cent. higher than the load, *i. e.*, the rated capacity was over twice as great as the load; and it never approaches it nearer than 25 per cent. on August 31, and 10 per cent. on September 7. The table shows, however, that in almost every case the conditions could have been greatly improved without overloading any of the machines, and if an allowable percentage of overloading were indulged in, a very much greater improvement could be made.

If the above suggestions were carried out in practice, there would not be the least element of danger introduced on account of running the machines near the limit of their rated capacity, as the overloading that every good machine can stand will amply provide for unusually rapid changes in the load.

The load diagram for every day in the week should be constructed and studied by the switchboard attendant, and he should also be informed regarding the load curves of each of the feeders leaving the station, in order that he may be able to make the best possible distribution of the load at all times. This end can, however, only be accomplished by having a very flexible arrangement of the switchboard connections and having the lighting circuits planned out and wired so as to come within the limit of the capacity of the various units.

There are some twelve incandescent circuits leaving the station, and it would appear that a more economical adjustment of the

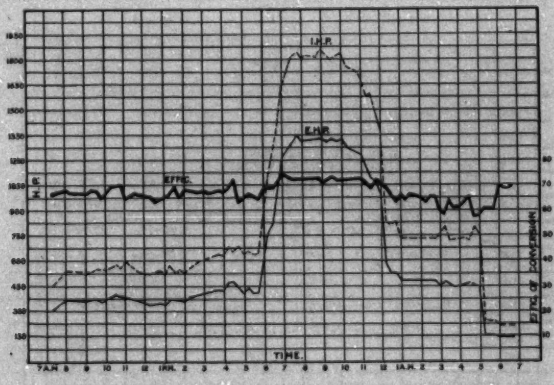


FIG. 15.—Pratt Street Station, Load Curves. Aug. 31, and Sept. 1. 1895.

load could be made were sufficient switchboard appliances provided. In spite of the fact that the load on the plant *never* reached the capacity of the machines in operation, some of the units were nevertheless overloaded at times, and in one instance alternator A was overloaded over 30 per cent. for quite a while.

It would appear from glancing over the records that engine No. 4 was needlessly operated for about four hours on August 31, and that engine No. 6 was run for even a longer period on September 7 without apparent cause.

These are the things that reduce the efficiency of a plant. They not only increase the losses between the boilers and the engines but also the losses between the engines and the switchboard.

Station Economy.

The Tests of the Station Lighting Plant.—As the heading implies, the matter that follows deals with the economy attained by the various equipments in the engine room, taken collectively, or as if they had formed but one unit. A log of the hours of starting up and stopping the engines on the two days, upon which tests of the plant were made, is given below in table 7. The data in the table only refer to the runs that were made by the en-

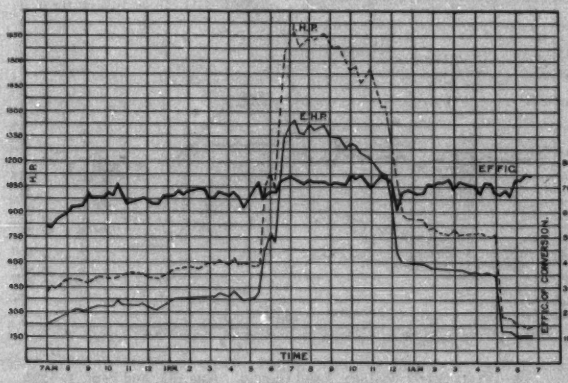


Fig. 16.—Pratt Street Station, Load Curves. Sept. 7 and 8, 1895.

gines for the purpose of developing electricity for the lighting circuits; it does not include the "friction runs." It will be noticed that the schedules upon which the engines were operated were very much the same on both days. The only differences of any importance were caused by interchanging the hours of operating engines Nos. 7 and 8.

The hourly records of the total indicated and electrical power developed by the station machinery are given in the graphical records constructed on Figs. 15 and 16. It is noticeable that the

station load diagrams bear a strong resemblance to the load diagrams of the arc lighting plant for corresponding days, and this is especially true of the load curve for the test of September 7. This is due to the fact that the differences between the day and night loads of the incandescent plant are not so marked as are those of the arc plant. The station load diagrams for the two days are also very much like one another, and except for the peaks on the curves of Sept. 7 and 8, that occur between 7 and 8 o'clock in the evening, the curves would practically coincide if plotted on the same chart. There is also a marked similarity in

TABLE 7.

HOURS OF STARTING AND STOPPING ENGINES.

No. of Engine.	August 31.			September 7.		
	Time of Starting.	Time of stopping.	Duration in hours.	Time of Starting.	Time of stopping.	Duration in hours.
1	5:50 P. M.	5:00 A. M.	11 16	5:30 P. M.	5:10 A. M.	11.67
2	7:00 A. M.	12:05 "	17.08	7:00 A. M.	12:05 "	17.08
3	7:00 "	12:05 "	17.08	7:00 "	12:05 "	17.08
3	5:00 "	6:00 "	1.00	5:20 "	5:45 "	.58
4	7:00 "	7:20 "	.33	6:45 P. M.	1:32 "	6.78
4	6:50 P. M.	10:45 P. M.	3.92			
5	7:00 A. M.	12:55 A. M.	18.92	7:00 A. M.	11:03 P. M.	16.05
6	7:20 "	10:55 "	3.58	7:00 "	1:20 "	6.33
7	2:00 P. M.	11:45 P. M.	9.75	6:30 P. M.	7:00 A. M.	12.50
8	10:45 A. M.	2:00 "	3.25	1:20 "	12:20 "	11.00
9	4:25 P. M.	6:55 A. M.	14.50			

the efficiency curves between the hours of 9 A. M. and 12 P. M. The low point at which the efficiency curve of Fig. 16 begins is due to the light load on the arc machinery at that time. The curve in Fig. 15 would have had the same appearance, probably, if the electrical readings from the arc machines No. 1, 2 and 3 had been obtained during the first hour of the run of Aug. 31.

Between 9 A. M. and 5:45 P. M. the I. H. P. curve rises gradually from 475 to 610 H. P. There is a noticeable drop in both the load and efficiency curves at noon when the arc motors are shut down, since the efficiency of the arc plant is lowered and the effect is necessarily transmitted to and made apparent in the station curves. During the day the efficiency averages about 67 per cent.

The heavy load comes on the station between 6:30 and 7 P. M. The load curves are rising very rapidly at this time, and the jump from 600 to 1800 H. P. takes place within an hour. As is to be expected, the efficiency of the station increases as the load comes on. Between 7 o'clock and midnight on Aug. 31, the load on the engines averages over 1700 H. P. and the efficiency of conversion fully 73 per cent. The efficiency attained on Sept. 7, during this period of the test averages about the same, although it is to be noticed that during the very height of the load, when the I. H. P. averages 1900 H. P. the efficiency is only about 71.5 per cent.

The lowering of the efficiency during the very heaviest load is rather peculiar. If we trace it back, we find that it comes from the load curves of the arc lighting plant and it can finally be traced to engine No. 1. At this time it will be remembered engine No. 1 indicated over 800 H. P., but an examination of the records shows that the equipment operated by this engine reaches its maximum efficiency when the engine indicates about 700 H. P. and that for loads above this value the efficiency falls off.

The greatest difference, however, between the efficiency curves of the two station tests occur during the early morning. Between 1 A. M. and 6 A. M. on Sept. 1, the load was carried by engines Nos. 8 and 1. Between 1 A. M. and 5 A. M. on Sept. 8, the load was carried by engines Nos. 7 and 1; and the variation in the efficiency is largely due to the better economy attained by the equipment driven by engine No. 7 relatively to that of the equipment driven by engine No. 8. The variation in the efficiency of engine No. 1, on the two mornings is also marked, and No. 8 is really only about half responsible for the drop in the curve.

Summing up the results, it appears that:—

	Aug. 31.	Sept. 7.
The maximum I. H. P. developed is	1863	1975
The maximum E. H. P. developed is	1347	1421
The average I. H. P. developed is	863	885
The average E. H. P. developed is	601	629
The average efficiency of conversion is	68.10	68.50

The average efficiency attained is excellent, and shows that the station is operated far more efficiently than is to be expected when the numerous drawbacks that have to be contended with

are remembered. A high *average* efficiency means much more than a high "apparent" or, more properly perhaps, a high "commercial" efficiency. *A high average efficiency* means that the plant is working economically *all the time*, for a low efficiency of conversion maintained for a very few hours will play havoc with the average efficiency for the day.

As an example of this it is worth while to recall the average efficiency of 73 per cent. maintained by engine No. 5 for a period of 16 hours on Sept. 7. The apparent or commercial efficiency of this equipment was also 73 per cent. *A low average efficiency* means that the plant is working uneconomically all the time or very uneconomically part of the time. As an example of this, it is only necessary to turn to the test of the arc lighting plant for Sept. 7. The commercial efficiency developed by this plant was 68.31 per cent. and the average efficiency of the plant was 62 per cent.

The commercial efficiency of the station on Aug. 31, was 70 per cent. and the commercial efficiency on Sept 7, was 71 per cent. These figures speak for themselves, and are values not often attained with the prevailing central station methods.

As regards the distribution of the load on the station throughout the entire 24 hours it is interesting to note that 42 per cent. of the total watt-hour output of the station is developed during the five hours preceding midnight. The remaining 57 per cent. is distributed fairly evenly over the rest of the day. During the heavy load 8.6 per cent. of the total daily output of the station is developed per hour, while during the other portions of the day only about 3 per cent. per hour is developed.

The Engines and Dynamos:—A review of the results obtained during the tests of the machinery in the engine room will necessarily involve numerous comparisons.

In table 9 a complete summary is given of the economic performance of all the equipments and of the station.

These results have been collected from the data given in the reports on the several equipments, and the quantities tabulated are primarily based upon measurements taken from the indicator cards.

In the case of engine No. 1, however, the water consumption is based upon the results of the special test made upon it on Sept. 1, and the values given for the water economy of the station are deducted from the general results of the tests as follows:

TABLE 8.

STATION ECONOMY.

Items.	Aug. 31.	Sept. 7.
1. Pounds of water actually evaporated corrected for moisture	513304	511992
2. Pounds water actually evaporated per hour corrected for moisture	21390	21330
3. Pounds of dry coal actually fired to the boilers	71506	72667
4. Pounds of dry coal actually fired to the boilers per hour	2980	2985
5. Average I. H. P. developed by engines	862.8	885.3
6. Average E. H. P. developed by dynamos		
7. Commercial efficiency	69.68	71.11
8. Average pounds water per I. H. P. per hour	24.79	24.90
9. Average pounds coal per I. H. P. per hour	3.454	3.372
10. Watt-hour output per lb. of coal	150.5	157.3

Referring to table 8, items 1 and 3 were taken from the boiler reports, and items 5 and 6 are the averages of the total horse-power records. The commercial efficiency is the ratio of the average E. H. P. to the average I. H. P. and it is made use of in deriving item 10 from item 9. In table 9 the "pounds of coal per I. H. P. per hour" are obtained by dividing the "pounds of water per I. H. P. per hour" by the economic evaparation of the boilers. The watt-hour output is obtained from the "coal per I. H. P." as stated above.

Table 9 also contains the average results of the horse-power records, the average efficiencies of conversion, the commercial efficiencies of all the equipments of the arc and incandescent lighting plants and of the station. It is an interesting fact that a comparison of the "average" and "commercial" efficiencies shows in every case whether or not there is a great variation in the hourly efficiency of conversion of an equipment.

Table 9 also contains a comparison of the actual average water consumption per I. H. P. per hour, with the average water consumption of the engines per I. H P. per hour calculated upon the basis of the water consumption of the engines determined from the indicator cards, and the per cent. of the total output of the station developed by the corresponding equipments.

The calculated average water consumption per I. H. P. per hour for August 31 is 31.18 pounds of water which is 20.60 per cent. greater than the actual average water consumption. The calculated result for September 7 is 28.66 pounds of water per I. H. P. per hour, which is 16 per cent. higher than the actual water consumption.

The differences between the actual and calculated values are partly due to the fact that the water consumption of the engines was not constant for all loads as it is assumed to be, since the water consumptions were figured from cards that showed an indicated power equal to the average indicated power of the engines. It must also be remembered that the amounts of the leakage that was present in the cylinders and valves of engines No. 1 and No. 8, are quantities that undoubtedly varied at times. The comparison is valuable since it shows that the water consumption credited to the engines is at least *not too low*.

The general summary contained in the table just described shows that the greater part of the output of the incandescent plant was carried by its most efficient units, engines 5 and 7, and that consequently the average commercial efficiency and water economy of the incandescent plant are higher than the corresponding results for the arc plant. Although the incandescent plant developed 52.7 per cent. of the total output of the plant, it required only about 42 per cent. of the total amounts of water and coal that were used on August 31. On September 7, owing to the fact that engine No. 8 was not operated for so long a time and engine No. 7 substituted for it, the economy of the plant is even better and apparently it consumed only 40 per cent. of the coal and water, while at the same time it developed a commercial efficiency of 73.8 per cent.

The arc lighting plant necessarily, in view of what has just been said, suffers by comparison with the incandescent lighting plant. The great difference in the economy is due to the fact that the arc lighting equipment is working at a disadvantage from every point of view. Not only is the electrical efficiency of arc lighting dynamos lower than that of incandescent machines, but the additional shafting and belting necessary for their operation introduces still other disturbing elements. When to these things is added the fact that the engines themselves are relatively less efficient than the engines driving the incandescent machinery, it is not surprising that they do not make a better showing. The

mere fact that engine No. 1, which operates an equipment developing 36 per cent. of the total output, requires over 30 pounds of water per I. H. P. per hour, is sufficient to explain any difference in economy.

TABLE. 9.

ECONOMY RECORD.

No of Engine.	Pounds water per I. H. P. per hour.		Pounds coal per I. H. P. per hour.		Watt-hour output per lb. of coal.		Dynamo driven by engine No.	Total watt-hour output.		Output in per cent. of station watt-hour putput.	
	Aug. 31.	Sept. 7.	Aug. 31.	Sept. 7.	Aug. 32.	Sept. 7.		Aug. 31.	Sept. 7.	Ang. 31.	Sept. 7.
1	32.96	32.96	4.584	4.682	114.30	114.8	1	3509000	3946000	37.75	35.02
2	32.81	34.52	4.571	4.904	116.70	96.80	2	1014000	819000	9.42	7.27
3	42.59	42.59	5.922	6.049	80.08	72.30	3	564600	546600	6.07	4.85
4	25.87	25.52	3.604	3.625	128.31	127.79	4	140350	541300	1.30	4.80
5	22.42	22.42	3.118	3.185	171.98	171.29	5	2122900	1942200	19.73	17.23
6	22.55	22.55	3.136	3.203	156.71	152.80	6	349650	542900	3.25	4.82
7	21.49	21.49	2.988	3.053	162.60	179.60	7	949100	1542300	8.82	13.68
8	29.03	29.03	4.037	4.124	127.30	131.00	8	2120000	1389400	19.61	12.33
Station.	24.79	24.09	3.454	3.372	150.5	157.3	Arc.	5088800	5311600	47.28	47.14
.....	Sept. 1.	.....	Sept. 1.	.....	Sept. 1.	.....	Incan	5674000	5958100	52.72	52.86
1	32.96	.....	3.18	.....	158.5	.....	Station.	10761800	11270700	100.00	100.00

No. of Engine.	Pounds water per I. H. P. per hour.		Proportional part of water used by engine		Average indicated horse-power.		Average electrical horse-power.		Average efficiency of conversion.		Commercial efficiency.	Commercial efficiency.
	Aug. 31.	Sept. 7.	Aug. 31.	Sept. 7.	Ang. 31.	Sept. 7.	Aug. 31.	Sept. 7.	Aug. 31.	Sept. 7.	Aug. 31.	Sept. 7.
1	32.96	32.96	12.44	11.54	588.00	644.15	413.09	460.05	68.8	71.03	70.22	71.41
2	32.81	34.52	3.09	2.51	110.10	100.71	76.80	63.65	69.6	64.3	71.51	63.21
3	42.59	42.59	2.58	2.06	71.94	72.53	45.75	42.47	55.2	51.3	63.60	58.55
4	25.87	25.52	.34	1.29	115.08	126.17	70.4	78.4	61.9	62.1	61.97	62.14
5	22.42	22.42	4.42	3.86	214.70	218.95	154.70	160.20	72.9	75.1	72.03	73.16
6	22.55	22.55	.73	1.08	179.43	170.51	117.21	111.95	65.90	65.6	65.32	65.66
7	21.49	21.49	1.89	2.94	203.12	217.62	132.54	159.30	63.80	73.5	65.23	73.20
8	29.03	29.03	5.69	3.45	226.79	232.12	157.3	169.3	68.90	72.4	69.33	72.92
Arc.	.....	.....	.....	.....	404.8	434.3	284.2	296.7	66.23	61.90	70.21	68.31
Incan.	.....	.....	.....	.....	458.0	451.0	317.0	332.8	69.00	71.00	69.20	73.80
Station.	Real 24.79	24.09	.....	.....	862.8	885.30	601.2	629.5	68.10	68.50	69.68	71.11
	Calculated											
Data.	31.2	28.66	Special test of engine No. 2		Sept. 1.	.....	Sept. 1.	.....	Sept. 1.	.....	Sept. 1.	.....
					553.82	.....	382.6	.....	66.7	.....	69.08	.....

Per cent. excess of the calculated water consumption of the station above the actual water consumption, Aug. 31, 20.60, Sept. 7, 16.00.

The effect that the engines have upon the average water consumption of the station is very well illustrated in Figs. 3 and 4.

In the mornings when engines 2, 3, 6 and 5 are in operation, the water rate averages 32 pounds of water per I. H. P. per hour on August 31, and 28 pounds per I. H. P. per hour on September 7. The difference is due to the fact that the morning load was lighter on September 7 than on August 31, and consequently the engines, especially engines 2 and 3, were relatively less efficient.

During the latter part of the test of August 31, the water rate falls to about 21.5 pounds per I. H. P. per hour, which is a remarkably good showing and indicates that some of the engines, probably Nos. 5 and 7, were operating very efficiently. At the same time on September 7 the water rate is somewhat higher. It averages fully 22.5 pounds of water to the horse-power, and the difference is probably due to the fact that engine No. 1 required more water proportionally on the latter night owing to its heavier load.

The coal economy can hardly be approximated from the curves owing to the fact that they are so very irregular. If it were possible to have the firing done constantly and regularly it might then be possible to obtain more uniform results for plotting purposes, but where it is only done at intervals, "when the fires seem to need more coal," very regular results cannot be obtained.

It may be interesting, in connection with this review, to estimate what maximum economy could be secured under the most favorable conditions which it is probable could be obtained at the station.

If we assume that the boilers in service are kept loaded to their full capacity, they will probably develop an economic evaporation of 10 pounds of water per pound of coal. This figure is slightly less than the actual evaporation per pound of coal developed by boilers 6, 7 and 8 on the night of September 7. Furthermore, if the engines and dynamos are kept up to the point of their maximum efficiency; if there are no leaks in the valves or past the pistons of the engines, if the governors and valves are properly adjusted to give the most economical distribution of the steam between the cylinders of the engines, if the dynamos are kept in good order, with well balanced armatures, low resistance contacts and sparkless commutation, and if good lubrication is maintained and all line shafts and bearings are kept properly lined up, then an economy such as is outlined in table 10 may possibly be

secured. This table represents the high-water mark of economy of the station. It may be thought that the values given are rather extreme, and that the percentage increase represents an impossible gain in economy, and yet it can be demonstrated that there are power plants of similar and even smaller capacity that are giving better results than these figures indicate. The plants referred to are not, however, electric lighting plants. It must furthermore be remembered that a very large proportion of this increase, in fact 40 odd per cent. of it would be due to the increased economic evaporation of the boilers, and it cannot for a moment be questioned but that the station economy has been greatly improved in this direction.

TABLE 10.

MAXIMUM ECONOMY.

No of Engine.	Average I. H. P.	Average E. H. P.	Average efficiency of conversion.	Lbs. water per I. H. P. per hour.	Pounds coal per I. H. P. per hour.	Watt-hour output per lb. of coal.	Per cent. increase in output.
1	600	420	74.0	18	1.8	307	167
2	170	131	77.0	28	2.8	205	75.
3	135	103	76.0	30	3.0	189	51.
4	145	106	73.0	21	2.1	259	100.
5	260	201	77.3	19	1.9	303	76.
6	145	106	73.0	21	2.1	259	66.
7	270	201	75.0	19	1.9	294	63.
8	260	201	77.3	19	1.9	303	132.

In the report presented to the *National Electric Light Association* on May 7, 1896, by its committee on data, attention is called to the fact that in a recent statement of the economy of the Chestnut Hill Pumping Station, at Boston, it was found that in actual water lifted, a horse-power was produced by the consumption of 1.34 pounds of coal. Assuming that the efficiency of pumps compares favorably with the efficiency of generators, and making no allowance for variation in load, one pound of anthracite coal used with the same economy in electrical work should produce 557 watt-hours. Although it is not to be forgotten that the economy reported for the pumping station was obtained under most favorable conditions, with dry high pressure steam and multiple cylinder engines, and although the relative conditions under which it and the present tests were made are not at

all comparable, the fact still remains that the report represents an economy of 400 watt-hours per pound of coal over and above the economy of the Pratt Street Station, or in other words it represents an increased economy of 255 per cent.

Now under the conditions outlined in table 10 the station would develop an economy of about 300 watt-hours per pound of coal. This would be an increase of 91 per cent. over its present economy and certainly represents a result worth striving for.

Now that we have discussed what the station could do under favorable conditions, let us see what it does do under actual conditions in comparison with other central stations of the country. This side of the situation is certainly as interesting as the other, since it brings us into immediate touch with the commercial competitors with whom the station has to contend.

For this purpose we cannot do better than turn again to the report of 1896 of the committee of the *National Electric Light Association*. The information published is certainly not below the economy of the stations represented, as contributors would tend to over-rate rather than under-rate their equipments in gauging their output; and again, we have the statement of the committee to the effect that although it realizes "that in the case of alternating currents the product of the amperes times the volts may not give the absolute watts, this method has been considered sufficiently accurate for this work." Of course "this method" increases the figure for the watt-hour output above its true value.

It is also certain that the statements contained in the report have been obtained from thoroughly representative plants, as their watt-hour per day output is too large for them to be otherwise.

Referring to the data contained in the report we find that the Pratt Street Station stands 15th in the order of the merit of producing the greatest watt-hour output per pound of coal; 15th in a list of 82 stations represented. Of the 14 stations that give a better record of economy only 3 have a greater watt-hour output per day. Of all the plants represented 7 have greater watt-hour outputs per day. "The average efficiency of the 81 reports using coal as fuel is 108 watts-hours per pound of coal," and the Pratt Street Station shows an economy of 45 per cent. in excess of this figure. One station, that has a watt hour per day output of 3207392 watt-hours, reports an economy of 237 watt-hours per pound of coal. The Pratt Street Station develops 65 per cent. of this economy.

The average watt-hour output of all the 14 plants that show a greater economy than the Pratt Street Station is 175 watt-hours per pound of coal, and the Pratt Street Station develops 90 per cent. of this economy.

All the plants that make a better showing than the subject of this paper seem to be better equipped from an economic standpoint.

Of the fourteen, three are equipped with triple expansion condensing engines; six are equipped with compound Corliss condensing engines; one is equipped with simple condensing Corliss, and high speed compound condensing engines belted direct to dynamos: three are equipped with high speed compound condensing engines belted direct to dynamos; and one with simple high speed condensing engines, belted direct to the dynamos. As regards their electrical machinery, two are equipped with direct connected multipolar dynamos; three are equipped with alternating current dynamos; one is equipped with bi-polar dynamos belted from jack shaft; and in the copy of the report that I have the others are not designated. In five of these plants water tube boilers are used alone; in two of them water tube and horizontal tubular boilers are used; and in the others horizontal tubular boilers are used alone.

It will be noted that the engines of the above mentioned plants are condensing, and it will be interesting now to review the non-condensing plants.

Of the 82 plants reported upon, 44 of them are operated with non-condensing engines. Of these, a number seem to be very well equipped. For instance, two are reported having compound Corliss and high speed compound engines, water tube boilers and alternating current dynamos. Six others are reported as having high speed compound engines, with various types of dynamos and boilers, and in only one of them do the dynamos seem to be belted from jack-shafts.

In speaking of the plants that are running with non-condensing engines, the committee makes the following comparison:

"In engine efficiency, eight stations report the water consumption per I. H. P. The triple expansions lead in economy, report 80 showing a consumption of 15.5 pounds, and report 3 showing 18 pounds of water per I. H. P.; these comparing reasonably with report 29, where an I. H. P. is produced by non-condensing engines with 26 pounds of water."

In the Pratt Street Station an indicated horse power is developed with 24 pounds of water.

The committee further says:

"Attention is called to the reports from plants running with non-condensing engines, in which report 26 is able to show 129 watt-hours per pound of coal; report 32, 113 watt-hours; report 33, 109 watt-hours; report 37, 100 watt-hours; and report 38, 95 watt-hours."

The Pratt Street Station shows an economy of 157 *watt-hours per pound of coal. and develops an economy* 22 *per cent. in excess of the best showing made by the* 44 *plants running with non-condensing engines.*

A Paper presented at the 124th Meeting of the American Institute of Electrical Engineers, New York, April 27th, 1898, Mr. H. Ward Leonard in the Chair.

A NOVEL FORM OF THERMO-ELECTRIC BATTERY.

BY O. J. REED.

If further proof were needed of the very high thermo-electric power of metals in contacts with electrolytes, a very striking and conclusive proof may be found in the following experiments.

The apparatus consists of a fused mass of caustic potash or soda maintained at a temperature of 500° to 800° C. into which two conducting rods are inserted, both of the same metal and as nearly alike as possible in every respect except form. One of the rods, marked B in Figs. 1 and 2, is of cylindrical form. The other, marked A, is in the form of a cylinder having a deep recess cut or turned out near one end, leaving at the end a short cylindrical head attached to the rod by a very narrow stem.

In order to obtain two pieces of metal having, as nearly as possible, the same molecular structure and chemical composition, a uniform rod of Bessemer steel $\frac{5}{16}$ inch in diameter and two feet long, was cut in two equal parts. The severed ends which were originally together at the middle of the rod are turned smooth and flat to form the lower or contact ends of the rods, A and B, shown in Figs. 1 and 2. The head formed on the end of A is $\frac{1}{4}$ inch long and the stem by which it is attached is half an inch long and $\frac{1}{20}$ inch in diameter. The two rods thus prepared are held parallel to each other and about $\frac{1}{4}$ inch apart in a wooden clamp with their ends in the same plane at right angles to their axes.

The rods are now inserted in a vertical position to a depth of $\frac{1}{2}$ inch into the fused caustic alkali. The surface of the fused alkali should come above the head of the rod, A, but not above the stem, as shown in Fig. 2. The cup used in this experiment to

hold the molten alkali is of sheet steel about two inches in diameter and three inches deep. The rods are inserted in the center of the cup, in order that the temperature and chemical composition of the mass of alkali immediately surrounding the rods, as well as the temperature of the air surrounding them may be as nearly homogeneous as possible. By these precautions all effects of every nature are eliminated, except such as may be due to the difference in temperature between the submerged ends of the two rods caused by their difference in form, which enables the rod, B, to get rid of its communicated heat by conduction more rapidly than the rod, A. The temperature of the alkali is maintained at about 700° C. After the rods have remained in the melted alkali a few minutes and the room has been darkened,

FIG. 1.

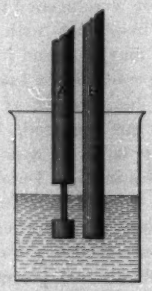


FIG. 2.

they are quickly withdrawn for inspection. The cylindrical head on the rod, A, is seen to be at a uniform bright red heat, while the rod, B, is only perceptibly dull red at the extreme end. The difference in temperature between the cylindrical head of A and the hottest part of B is probably not less than 100° C. The reason for this difference in temperature is apparent. The narrow stem of A conducts heat away very slowly, while the rod, B, of uniform diameter conducts away its heat with a rapidity many times greater. Assuming that both rods receive heat from the surrounding liquid initially at the same rate per unit of surface, the head of rod, A, must become much hotter than any part of B, since it has a relatively larger surface of contact with the communicating liquid and loses its heat by conduction much more slowly.

In this arrangement we have two pieces of metal as nearly alike as possible in chemical composition and molecular structure, subjected to the same conditions in all respects, except that the temperature of one at its junction with the electrolyte is higher than the temperature of the other at its junction with the electrolyte. In other words, the electrolyte has one hot and one cold junction with pieces of the same metal inserted in it to the same depth and subjected as far as known to no other disturbing influences.

This arrangement gives an electromotive force, varying with the temperature and constitution of the electrolyte between — 0.2 volt and + 1 volt. The difference in temperature between the two junctions evidently increases with the temperature of the fused alkali, being zero when the temperature of the communicating liquid is the same as that of the surrounding air. The difference in temperature between the junctions increases rapidly for a certain period from the beginning of the experiment, while the rod, B, is comparatively cold and capable of dissipating heat rapidly and while the temperature of A is rapidly rising. Following this will be a period, during which the difference in temperature between the junctions will diminish until both rods attain throughout their entire lengths the maximum temperatures they are capable of attaining under the conditions.

I have previously shown [1] some of the peculiar variations of electromotive force under changes of temperature and alterations in the constitution of the electrolyte, which are exhibited in a cell consisting of an iron cup containing fused alkali as one electrode and an iron or other conducting rod inserted in the alkali as the other electrode. In that apparatus the iron cup imparted heat to the alkali and the alkali imparted heat to the rod. From this circumstance it follows that the junction of the electrolyte with the iron cup is necessarily hotter than the junction of the electrolyte with the rod. The cup, being the hotter of the two pieces of iron in that experiment, should act in the same qualitative manner as the rod, A, in the experiment illustrated in Fig. 2 above, A being the hotter of the two rods. But the difference in temperature between the two rods, A and B, can never be as great as the difference between that of the heated cup and that of the rod, B. These conclusions are entirely con-

1 See *Electrical World*, July 25, 1896.

firmed by the experiment, the rod, A, acting in the same manner as the cup, with the exception that the electromotive force obtained from it is not so great.

In attempting to explain the electromotive force developed between the heated cup and the inserted rod as a result of chemical action, some have resorted to the argument that the upper layers of the liquid may have an affinity for iron different from that of the lower layers, assuming that oxidation of iron in the upper layers causes reduction of iron in the lower layers and at the same time evolves electrical energy. The experiment with the two rods inserted to equal depths evidently leaves no room for such an argument, aside from its inherent absurdity. As a matter of fact there is no evidence of the existence of any such layers of varying chemical composition, the entire mass being continually stirred up by rapid convection currents like boiling water. The same results are obtained even when the rods extend to within a millimeter of the bottom of the cup. I have also obtained an electromotive force of nearly one volt between the cup and an inserted iron rod when the rod actually rested on the bottom of the cup, metallic contact being prevented only by a thin film of oxide or of the electrolyte.

Admitting that the chemical affinity between hot iron and the electrolyte is undoubtedly different from that between cold iron and the electrolyte, no energy could be evolved in any form due to this differential affinity, except energy derived from the heat of the furnace, since the existence of this differential affinity depends only upon the difference in temperature. To suppose that the electrical energy of this cell is derived from chemical action, involves the assumption that iron has a greater affinity than *iron* for oxygen, or that oxygen will select and combine with one of two similar pieces of iron while it dissociates from the other, and the further assumption that such a process will evolve energy. If this is possible, it can be possible only because of the difference in temperature, which in turn can be maintained only by a constant expenditure of heat from the furnace. Otherwise we should have an inexhaustible source of energy. If oxygen can evolve energy by leaving one piece of iron and combining with another, it may, with equal reason, leave the second and re-combine with the first, evolving an equal amount of energy, and there would be no limit to the number of such reversals, all evolving energy.

The experiment shows that the rods, A and B, evolve electrical energy and exhibit a high electromotive force under circumstances that are identical in all respects except temperature, and that the action is, therefore, thermo-electric.

The experiment may be varied by using two rods in the form of B. In this experiment there is no evidence of electromotive force when the rods are in a vertical position, so that both are equally heated by the electrolyte, as shown in Fig. 3. Upon inclining the rods so that one barely makes contact with the electrolyte, while the other extends about a quarter of an inch below the surface, as shown in Fig. 4, the rods acquire a considerable difference in temperature, which is clearly indicated to the eye, one being distinctly red and the other black. At the same time an electromotive force is developed, which in some

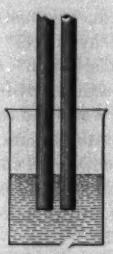


FIG. 3.

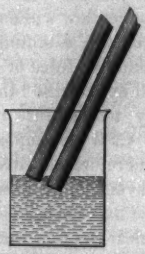


FIG. 4.

experiments has reached as high as 0.6 volt. Upon reversing the position of the rods, so that the hot one becomes cold and the cold one hot, the direction of the electromotive force slowly reverses. This reversal I have found may be repeated indefinitely, provided the other conditions of the experiment are maintained.

Rods of carbon, copper and various other metals may be substituted for the iron rods, and other electrolytes substituted for the caustic alkali. In all cases similar results, differing only in degree, are obtained. Many of these results are highly interesting and will be described later in detail.

The changes in the constitution of the alkali hydrate, which take place during its gradual dehydration have not yet been definitely determined. It is quite certain that these changes have a marked effect on the thermo-electric power of the cell.

If any current be allowed to flow, the electrolytic action of the current immediately causes the formation of oxide of iron at one electrode and the reduction of previously existing oxide of iron at the other electrode. This necessarily produces a change of chemical composition in the electrolyte adjacent to the electrodes or on the surface of the electrodes themselves.

As long as oxide of iron remains dissolved in the electrolyte and in contact with the electrodes in sufficient quantity to transmit the current, the electrolytic action will neither absorb nor evolve energy, since the amount of iron oxidized at one electrode will be equal to the amount reduced at the other. The resistance of the electrolyte as a conductor only will cause a fall of the potential difference on closed circuit. If no oxide of iron is present in a dissolved condition in the electrolyte and if there is none on the surface of the hydrogen electrode available for reduction, the current can no longer flow without reducing some other constituent of the electrolyte, such as sodium or hydrogen. In other words, a counter-electromotive force or "polarization" ensues.

It was found by Deville [1] that sodium hydrate does not decompose at any temperature into water and sodium oxide, but at about 1100° C. it decomposes into sodium, hydrogen and oxygen. If, therefore, a condition should ensue, in which no oxide of iron is available for reduction while the current continues to flow and ferric oxide continues to form at the oxygen electrode, the electro-chemical reaction would be

$$3\,NaOH + 2\,Fe = Fe_2O_3 + 3\,Na + 3\,H.$$

This reaction could take place electrolytically at ordinary temperatures by the absorption of 115,000 calories, corresponding to a counter-electromotive force of $\frac{115{,}000}{6 \times 23{,}240} = 0.82$ volt. At the temperature of 500° C., at which the thermo-electromotive force of the cell is about 1 volt, the reaction would absorb approximately 72,000 calories, corresponding to a counter-electromotive force of $\frac{72{,}000}{6 \times 23{,}240} = 0.52$ volt.

There is reason to believe that this condition of the electrolyte does actually ensue at a certain stage of the experiment when the circuit is closed, and under certain conditions metallic sodium may be evolved in considerable quantities at the inner surface of

1 *Comptes Rendus*, xlv. 859.

the cup. The maximum quantity of iron that can be dissolved in the fused caustic alkali is very small, and this appears to be held in solution only while there is present more water than corresponds to the formula for the alkali hydrate. This excess of water is driven off very slowly, the last trace leaving only at a temperature above 500° C.

Liebenow and Strasser [1] found that when the alkali, fused in an iron cup, reaches a temperature of about 550° C. after prolonged heating, it undergoes a radical change in properties, changing color from green to dark brown and simultaneously absorbing heat and causing its own temperature to be temporarily reduced. With this change in the electrolyte the electromotive force undergoes a sudden change of about one volt.

The absorption of heat and consequent reduction of temperature can be accounted for only by a chemical change in the electrolyte which causes the heat to become latent. Such a reaction may be explained on the supposition that the electrolyte changes at this temperature from an aqueous solution to a dehydrated fused electrolyte. While water is present, the iron probably remains in solution as ferric acid (the highest known oxide of iron) in combination with the alkali as potassium or sodium ferrate, which in the highly concentrated solution has a green color if any sulphur is present. When the water which holds this salt in solution is finally driven out, the ferric acid, being insoluble in the dehydrated alkali hydrate, is decomposed into ferric oxide, potassic oxide and oxygen, the reaction being

$$2\,K_2FeO_4 = 2\,K_2O + Fe_2O_3 + 3\,O.$$

The insoluble ferric oxide precipitated in the solid state by this reaction gives the dark brown color to the mass, which was observed by Liebenow and Strasser. This precipitate is found disseminated through the solidified hydrate on cooling. The dissociation of the ferric acid should be accompanied by the absorption of considerable heat—probably at that temperature about 150,000 calories. This would be sufficient to account for the remarkable fall of temperature, observed by Liebenow and Strasser to accompany the change of color from green to brown. A further examination of the results obtained by these investigators reveals the fact that this fall of temperature occurred only in those experiments in which either iron or nickel was present in the electrolyte.

1 *Zeitschrift fur Elektrochemie*, Feb. 20, 1897.

The experiments referred to of Liebenow and Strasser are a series of elaborate investigations on a number of alkaline thermo-electric cells, the results of which are entirely in accord with the explanation given above, and form the basis on which that explanation is chiefly founded. I am unable to agree with those investigators, as before stated, in some of their conclusions; as, for instance, the conclusion that electrical energy or any other form of energy can be evolved from the "passivity" of a metal

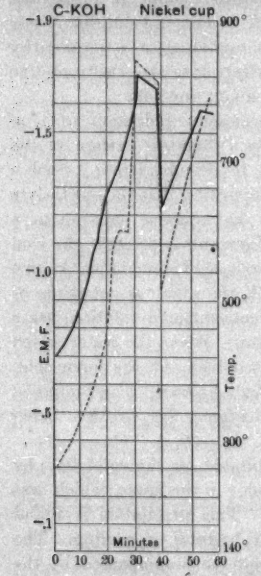


FIG. 5.

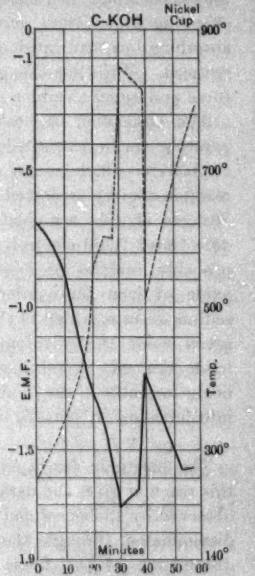


FIG. 6.

or from any other property of matter, and I believe the experiments they have described do more towards disproving their own preconceived theory than any experimental work that has been done relating to this subject.

In those experiments the effects produced by various alterations of the electrolyte on the potential difference between various electrodes and an arbitrary "normal electrode" were determined. Simultaneous measurements of electromotive force and tem-

perature were made which throw much light upon the nature of these cells. Unfortunately no measurements were made to determine at the same time the difference of temperature between the various electrodes.

The relation between the temperature of the electrolyte and the electromotive force of the carbon-caustic-potash cell, as indicated by the results of Liebenow and Strasser, is well illustrated in the curves shown in Fig. 5. In this diagram the abscissa represents the time measured from the beginning of the experiment, and the corresponding ordinate of the dotted line represents the temperature, while the ordinate of the full line represents the simultaneous difference of potential between the carbon rod and the "normal electrode." Liebenow and Strasser apparently failed to see the relation between the curves of temperature and electromotive force, simply because the direction of this electromotive force happened to be opposite to that which they had been arbitrarily measuring as increasing towards the top of the diagram. They, therefore, measured electromotive force downwards and the corresponding temperatures upwards and obtained the diagram shown in Fig. 6, which is not quite so easily interpreted. They apparently failed to get any meaning from it, merely remarking that it did not agree with the formula they had empirically deduced.

When the intensity of the electromotive force is compared directly with the temperature, instead of inversely, the relation becomes apparent, as shown in Fig 5. In this particular case the diagram shows decidedly that the electromotive force increases and decreases with the temperature of the electrolyte. From the nature and arrangement of the apparatus we know that the difference of temperature between the electrolyte and the rod will also increase and decrease with the temperature of the electrolyte. This dependence of electromotive force upon difference of temperature is shown in nearly all the diagrams of Liebenow and Strasser, when the electromotive force, whether positive or negative, is measured in the same direction as the temperature. And it must be so measured in order to make a direct comparison. The polarity or direction of the electromotive force has no particular bearing on the relation between its intensity and variations in temperature, but is dependent merely on the accidental position of the neutral point on the thermo-electric diagram.

When any thermo-electric couple is heated up from a very low to a very high temperature without any great change in the difference of temperature between the hot and cold junctions, the electromotive force will diminish with increase of temperature until the neutral point is reached, where it will become zero and change sign. From that point it will increase with the temperature if the difference in temperature between the junctions does not diminish.

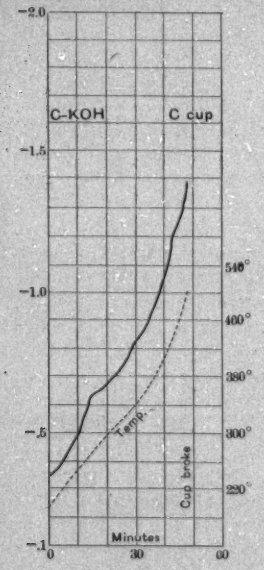


FIG. 7.

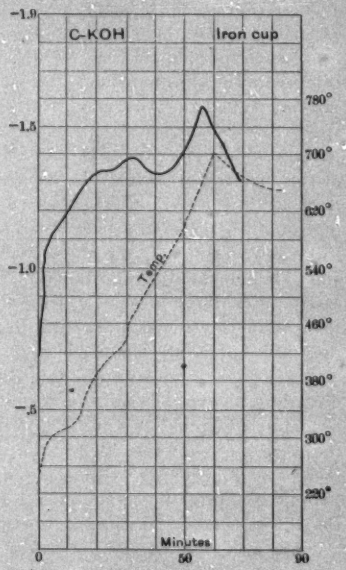


FIG. 8.

In the case shown in Fig. 5 it is evident that the electromotive force does not change sign. This means only that in this particular case (carbon-caustic-potash junction) the neutral point, if there be any, lies outside of the range of temperatures employed in this experiment, that is, the neutral point does not lie between 260° and 850° C.

When these facts are all taken into account the results obtained by Liebenow and Strasser, as far as they go, show that the

electromotive force was produced by and depended upon the difference of temperature between the rod and the electrolyte, except in those cases where they purposely introduced disturbing elements. In such cases they do not describe the details of their apparatus and *modus operandi* sufficiently to enable us to judge what effect upon the temperature of various parts of the apparatus may have been produced by the various gases they introduced in some of their experiments and by closing the crucible with a

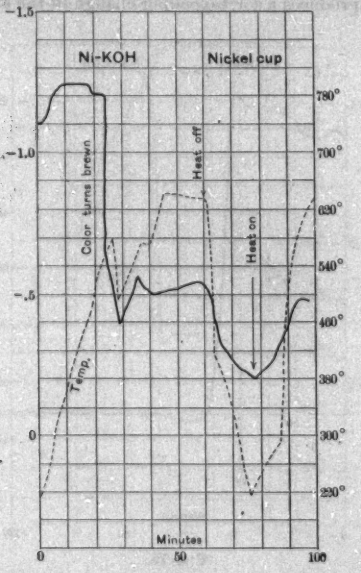


FIG. 9.

cover, which would naturally tend to keep the temperature of the rod and that of the electrolyte more nearly alike at the point of contact.

The experiment with the carbon rod and caustic potash was varied by Liebenow and Strasser by substituting for the nickel cup used in Fig. 5, in one case a carbon and in another case an iron cup. The results are exhibited (by inverting the curves of Liebenow and Strasser) in Figs. 7 and 8 respectively, which agree

with Fig. 5 in showing that the curve of electromotive force in the carbon-caustic-potash couple follows in general the curve of temperature, and that the neutral point of this couple does not lie between 200° and 700° C.

A second group of most instructive experiments with metal rods substituted for the carbon rod (the results of which are exhibited in Figs. 9, 10, 11 and 12) demonstrate in an equally convincing manner that a change in the temperature of the electrolyte produces a corresponding change in the electromotive

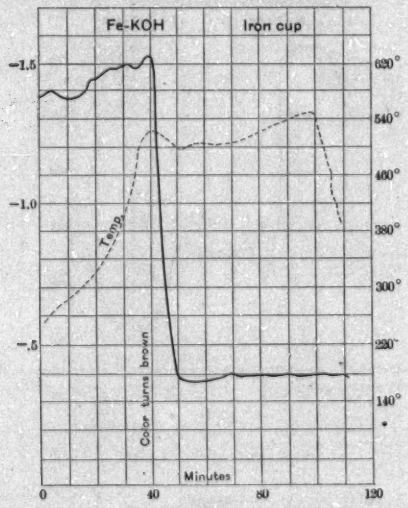


FIG. 10.

force. These curves were also inverted on the temperature curves in the diagrams of Liebenow and Strasser. In Fig. 9, showing the result when a nickel rod and cup are used, there are no less than eight well marked points of flexure in the temperature curve, each corresponding to a similar point in the curve of electromotive force. Fig. 11 differs from Fig. 10 only in the substitution of caustic soda for caustic potash.

An examination of these four curves shows some very instructive coincidences, among which are the following:

1. The electromotive force increases with increasing temperature from the beginning of the experiment up to the moment the brown color of the electrolyte appears, indicating a chemical change and probably a condition of dehydration. This change was not marked in Fig. 11 by Liebenow and Strasser, but the curves of electromotive force and temperature both show that it must have occurred at the end of 26 minutes.

2. When this point is reached there is a sudden and very great change in electromotive force.

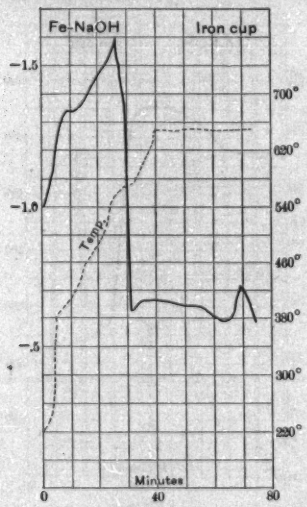


FIG. 11.

3. Simultaneous with this change of electromotive force and change of color, an absorption of heat occurs in the electrolyte, which causes a sudden reduction of its temperature. In Fig. 11 this reduction of temperature is indicated only by a flattened portion of the temperature curve. This reduction in the temperature of the electrolyte would necessarily greatly reduce the difference between its temperature and that of the metallic rod to which it communicates heat. It is conceivable that in some cases, where the absorption is very marked and sudden, heat

may actually flow back from the rod to the electrolyte. This sudden reduction in the temperature of the electrolyte accounts satisfactorily for the change of electromotive force accompanying it.

4. From this point to the end of the experiment the curve of electromotive force follows in general the temperature curve.

In all cases except that of silver, Fig. 12, the temperature at which the sudden change occurs, lies between 524° and 580° C. The more rapidly the heat is applied, the higher is the temper-

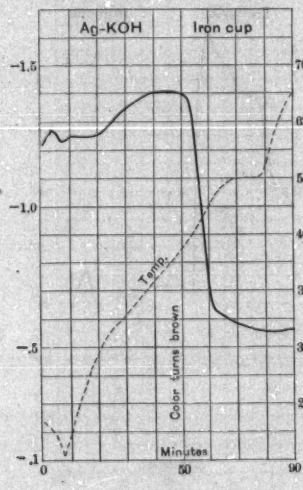


FIG. 12.

ature at which this change occurs and the more nearly vertical is the curve of electromotive force at that point. In Fig. 9 the dehydration point was reached in about 23 minutes and the temperature attained before the change was 580°. In Fig. 11 the time was about 26 minutes and the temperature attained 570°. In Fig. 10 the time was 40 minutes and the temperature 524.°

In Fig. 12 the time was 50 minutes, the temperature 460°, and no reduction of temperature was observed to accompany the change of color. This may be accounted for on the supposition

that, owing to the slowness of the reaction in this case the continuous application of external heat was sufficient to prevent an actual fall of temperature.

In Fig. 13 the conditions were the same as those of Fig. 12, excepting that a silver cup was substituted for the iron cup and, consequently, there was no iron present in the electrolyte. The marked irregularities in the curve of electromotive force shown in Fig. 13 are to be expected from the high thermal conductivity of the silver cup and rod, which makes the apparatus very sensitive to fluctuations in the source of heat. The absence of

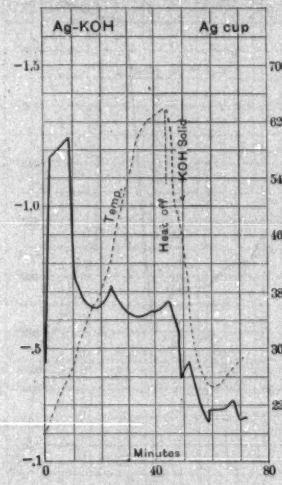


FIG. 13.

any indication of chemical change or change of color in the electrolyte or of any corresponding absorption of heat or change of electromotive force is accounted for by the fact that there is no iron or nickel in the solution and that the dehydration is accomplished without any chemical change due to the presence of impurities.

Figs. 14 and 15 show the result of substituting for the normal electrode in Figs. 8 and 6 respectively, rods of iron and nickel. The effect of this change was to remove the arbitrary zero of potential established by the introduction of the normal electrode

and to transfer the neutral point, at which the electromotive force changes sign, to a position within the diagram. The neutral point on these diagrams corresponds to the temperature of $555° \pm 5°$, coinciding with the temperature at which the chemical change and the absorption of heat occur. These curves are not inverted, but are copied without change from the curves given by Liebenow and Strasser.

In Figs. 16 and 17 the results are further complicated by the

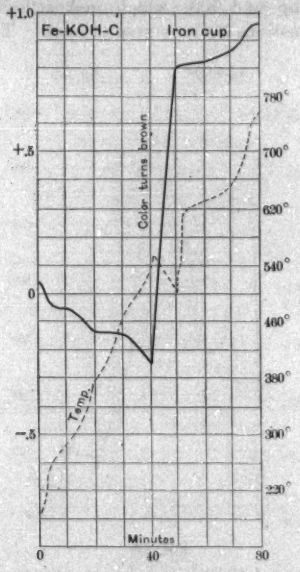


FIG. 14.

use of various disturbing influences. The most important change introduced in these experiments was to close the cup with a practically air-tight cover, through which a carbon and an iron rod were inserted. This entirely prevented the circulation of air over the surface of the electrolyte and around the lower ends of the rods. The temperature of such a closed chamber above the electrolyte would be only slightly less than that of the electrolyte itself after the apparatus had become thoroughly

heated. The lower ends of the carbon and iron rods, being surrounded by an atmosphere nearly as hot as the electrolyte, would have little difference in temperature at their surfaces of contact with the electrolyte, nothwithstanding their great difference in conductivity. Such an arrangement would result in a very much lower electromotive force. Liebenow and Strasser reported no experiments under exactly these conditions, but gave in Figs. 16 and 17 the results obtained by various modifications of these

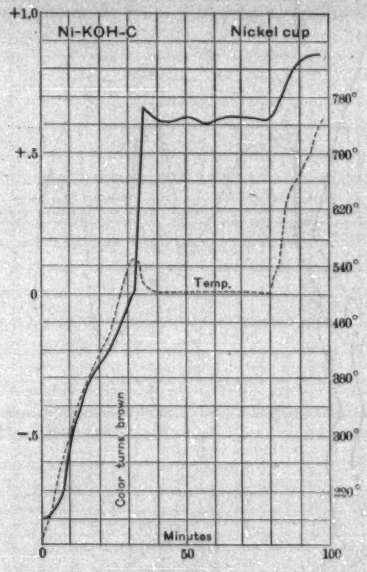


FIG. 15.

conditions, viz., by passing through the closed chamber various gases.

Unfortunately sufficient attention was not given to the details of these experiments to enable us to decide to what extent, if any, the results were due to the chemical action of the gases introduced, and to what extent they were due to their cooling effect. If the air and all the various gases were passed through the closed chamber at the same temperature and all with the

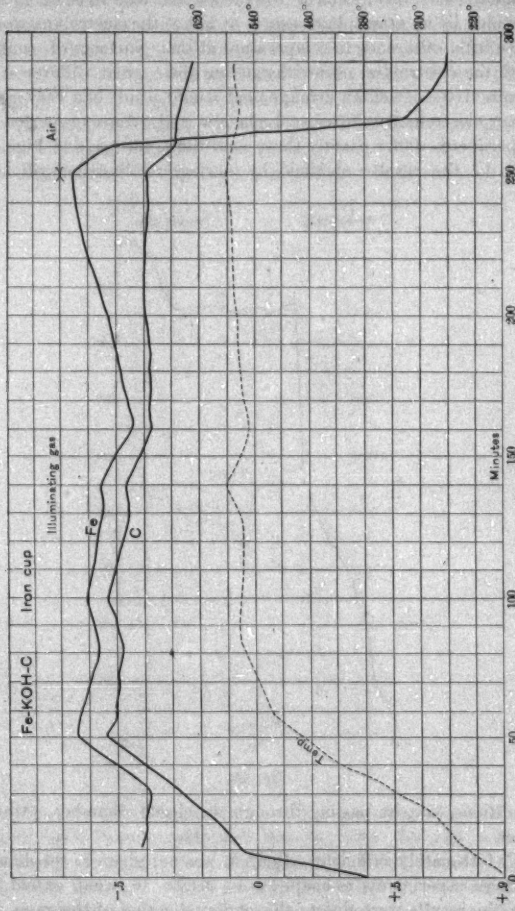


FIG. 16.

same velocity, the only difference in their cooling effects would be that due to the differences in their specific heats. These

could not be very great and would probably be negligible. If, on the other hand, the gases were passed through the cell with greatly varying velocities, their cooling effects, particularly on the iron rod, would be very different.

Fig. 16 shows the result obtained by passing illuminating gas through the cell for four hours and ten minutes, then replacing it by air. At the end of the first hour the temperature and the electromotive force became practically constant and remained so until the change was made from illuminating gas to air. When

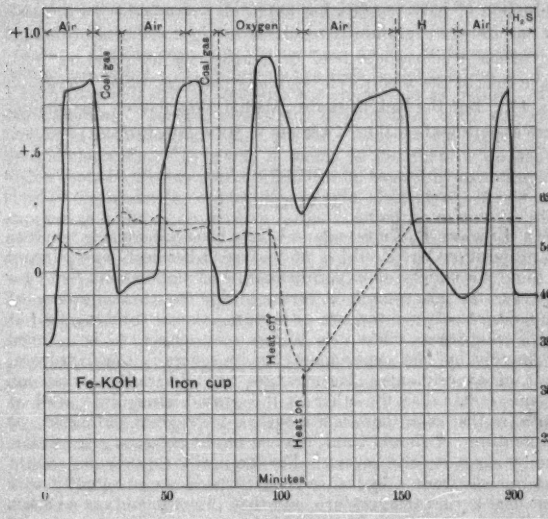


FIG. 17.

this change was made there was a noticeable, though not great fall in the temperature of the electrolyte, a corresponding change in the electromotive force of both the carbon and the iron as compared with the normal electrode, the change in the iron being very great. These curves, which are also the inverted curves of Liebenow and Strasser, are seen to follow the temperature curve in exactly the same manner as the curves of carbon and iron shown in Figs. 5 to 12.

In the absence of any statement to the contrary by Liebenow

and Strasser the inference is reasonable that the air forced through the cell was in a large or unlimited quantity, while the flow of the combustible gases was adjusted to make the issuing jet burn with as small a flame as possible. If such were the case, the cooling effect of the air on the rods could not fail to produce the result shown in Fig. 16. The same explanation applies with equal force to the results shown in Fig. 17, in which various gases were successively passed through the cell. There is no doubt that the results are also complicated by various chemical changes resulting from the gases introduced. The introduction of pure oxygen, for example, in contact with the red-hot carbon would certainly result in a vigorous combustion of the carbon, which would tend to increase its temperature even above that of the electrolyte and augment the effect shown in Fig. 17. But the lack of more detailed information concerning these experiments makes it useless to speculate further.

Discussion.

Mr. Edward P. Thompson:—I have been considering whether the proposition Mr. Reed has put before us has been strengthened by him by a variety of experiments. As I understand from his remarks, the electromotive force is due to the difference of temperature between the two electrodes. I was thinking that if that is what he considers it to be due to, it ought to be proved not merely by one experiment, but by several,—that is, several kinds of experiments. He arranges two electrodes so that one becomes hotter than the other by the heated electrolyte, and of course, in that case, there is not such a very great difference of temperature. I should think that he might obtain a great difference by some outside means. For example, suppose he should heat the electrode A by an outside furnace, so as to get it to a great deal higher temperature, and then insert it, and see whether the electromotive force has increased; or reverse the experiment by heating the electrode B, so that it is about as hot as electrode A, and see whether the electromotive force is zero. I am inclined to agree with Mr. Reed's presentation, but at the same time more than one kind of experiment should be in evidence.

It might be argued, although not on very solid grounds, that the reason why there is an electromotive force, is because there is less surface on one electrode than there is on the other. Now in Fig. 3, the two surfaces are equal, and there is no electromotive force. In Fig. 4 again the two surfaces are unequal and there is an electromotive force; so that a person, merely as a matter of argument, could say that the relative amounts of surface of the

two electrodes might have something to do with the production of current, although I do not think that he could uphold his argument.

Referring again to my first point, I would like to ask the author whether he has caused one of the electrodes like that in Fig. 3 to be heated to a great deal higher temperature by some *outside* source, for instance, by putting it into a furnace and then dipping it into the electrolyte; or it could be heated while it is in there by some convenient arrangement. It seems to me that the matter ought to be proved more conclusively by a variety of experiments.

MR. REED:—Those experiments have been tried, and I was going to try this evening the experiment of reversing the electrodes to show that the electromotive force is brought to zero and reversed. Then in regard to the surfaces, in Fig. 3 the surfaces of contact are equal. If we incline the rods in the position of Fig. 4 both rods will still be wet with the electrolyte as before. The same amount of surface would still be in contact with the electrolyte in both cases, although part of it may be in a thin layer on one electrode. However, it seems to me that if we are to argue that the electromotive force can be caused by exposing two similar electrodes to contact of a single electrolyte, if we can suppose that the electromotive force is caused by merely a difference in the surfaces in contact with the electrolyte, then we could get an electromotive force by using any electrolyte, inserting two pieces of iron of different sizes, or two pieces of zinc. It seems to me we could try innumerable experiments of that kind, and I guess they have been tried to the satisfaction of every one who has tried to get energy in that way. We certainly could not get electrical energy by inserting two pieces of zinc or anything else into an electrolyte, simply by inserting one to a greater depth or giving it a greater contact of surface. If we could, that would be a cheap way of getting energy. I do not know whether that answers the question.

MR. THOMPSON:—That was merely a superficial argument. I did not believe in it at all myself; only I said it was an argument a person could present. But the principal one, is whether you have heated one electrode from an outside source to a great deal higher temperature than that of the other and whether you obtained better results.

MR. REED:—Yes; I have tried a great many experiments of that kind which were entirely satisfactory. I did not think it was worth while to take the time of the INSTITUTE to enumerate them all in this paper, and I tried a great many different electrolytes and other substances besides iron. I will say that this question of the thermo-electromotive force of a metal in contact with an electrolyte has been investigated by quite a number of observers. Nearly twenty years ago Bouty made some experiments to determine the electromotive force of contact between

electrodes and electrolytes (see Fig. 18). Bouty took two test tubes filled with an electrolyte; sulphate of zinc was one electrolyte on which he experimented; then connected them with a small tube filled with the same solution, inserted a thermometer into each and also a piece of amalgamated zinc. Then he surrounded one of the tubes with water, maintained at zero or some fixed temperature, and the other with water which he kept at a different temperature. In that way he determined the electromotive force between the two pieces of zinc inserted in the zinc sulphate, one piece being at a different temperature from the other. He determined this electromotive force with reference to a number of electrolytes. The same thing was done later by Chroustchoff and Sitnikoff and also by Carhart. They all found that the results agreed with the formula for the relation between the electromotive force and the chemical energy of the reaction

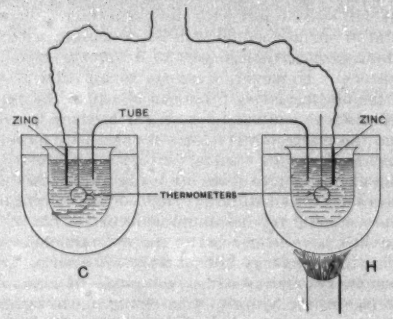


FIG. 18.

between the electrolyte and the electrode, plus or minus the thermo-electromotive force of the circuit which Helmholtz showed to be equal $t\frac{dE'}{dt}$; that is, the absolute temperature into the first differential coefficient of the thermo-electromotive force with respect to the temperature. The results all agree in showing this formula to be correct; but they all claim that this thermo-electromotive force was due entirely to the Peltier effect; that is; due to the electromotive force of contact between the electrode and the electrolyte, and I think none of their experiments proved that. Their experiments merely showed the thermo-electromotive force. They did not show that it was due to the Peltier effect alone. In reality you will see that what they determined was the thermo-electromotive force of the entire circuit composed of two conductors, one being the electrolyte, and the other being a

metal interrupted at one point, one point, H, of the circuit being heated and one point, C, being cold. There is nothing in their experiments to show that that electromotive force was due to the Peltier effect alone. If we simply take the figures they give and that arrangement it would indicate rather that it was due to the sum of the Thomson and Peltier effects. They made no measurements to determine the difference of temperature between the electrode and electrolyte. It is evident that the electrodes would have nearly the same temperature as the electrolyte in each case.

MR. C. O. MAILLOUX:—I am interested to know if among the electrolytes Mr. Reed has used he has tried any of the metals melting at a low temperature, such as fusible alloys, and even lead which could be retained fluid at the temperatures at which he has been working. If the function of the fluid is merely that of disseminating heat, it is improper to term it and treat it as an electrolyte; it is more a menstrum for the conveyance of heat. In that case, by the use of a metal instead of a liquid, he would avoid the phenomenon of polarization, because the only effect which could take place at the points of contact by the passage of current would be the Peltier phenomenon, which, while it would introduce an electromotive force, would be of opposite polarity at the two electrodes, and therefore would have no effect upon the resultant electromotive force.

MR. REED:—The question which has been in dispute, and which I attempted to determine by these experiments, was the fact that there is a high electromotive force, or thermo-electric power, I should say, between the fused electrolytes and solid conductors in contact with them. I did not know that there was any question about there being a thermo-electromotive force between metals in contact.

MR. MAILLOUX:—Perhaps I did not make myself sufficiently clear. I meant to say that if we were to substitute for the fluid, lead in a molten state at a temperature from 300 to 350° C, or at some temperature which is just below its evaporation or volatilization point (the melting point of lead being about 330° C.) and if at that temperature, under those conditions, we obtained practically the same electromotive force for the same difference of temperature between the electrodes,—that, it seems to me, would show conclusively, that the phenomenon was due entirely to difference of temperature, and that the term electrolyte was not applicable, and that the liquid was merely a convenient substance for disseminating or conveying heat. It seems to me that an experiment of that character would strengthen the position taken by Mr. Reed, if the results thereof showed that the electromotive force obtained was still a function of the difference of temperatures, the liquid substance merely serving as a means for the conveyance of heat and at the same time as a conductor.

MR. REED:—I do not think there is any question about there being thermo-electromotive force in circuits composed wholly

of metals. I consider that that question has been settled by the work of Kelvin, Tate and others a good many years ago.

MR. MAILLOUX:—Would the electromotive force be the same?

MR. REED:—No, very different. That is just the point which I originally noticed and which seemed to me a curious phenomenon and which induced me to investigate this subject further. I noticed that the electromotive force between the electrolyte and metals in contact was very much higher, in most cases hundreds of times as high as what we could obtain from a thermo-electric battery or junction consisting of metals. For instance, the thermo-electric power of any two metals is only a few millionths of a volt per degree centigrade; whereas with the electrolytes it is all the way from ten to a hundred times, or three or four hundred times as much. One of the first experiments which I observed in that connection was with two pieces of copper containing a thin film of copper oxide between them. They were placed in contact (two pieces of copper wire, for example), one of them may be heated only say one hundred degrees hotter than the other to get an electromotive force on nearly half a volt, as long as there is copper oxide between them. But as soon as the copper oxide is reduced by the passage of the current, or in any other way, and metallic contact occurs, the electromotive force drops so that you could not measure it with a voltmeter of this kind. In other words, if we take two pieces of metal in actual contact and heat one of them hotter than the other and get as great a difference in temperature as possible, we get a result which is not anything like what we get in the case of an electrolyte. I do not know whether that answers your question or not.

MR. MAILLOUX:—It answers it partly. The principal object of my question was to know whether if you were to substitute lead for the caustic potash there, the electromotive force would be approximately the same or not.

MR. REED:—Nothing like it. We have two pieces of iron here, and merely maintaining those two pieces of iron at slightly different temperatures and having them connected by melted lead would give us only a very small electromotive force; it would be the thermo-electromotive force of iron against lead.

MR. MAILLOUX:—What I mean is to repeat the experiment as shown in your Figure 2, using lead instead of caustic soda.

MR. REED:—You would not get any electromotive force to speak of.

MR. MAILLOUX:—You still get the same difference of temperature between two rods, owing to the difference at which the heat would be disseminated. One would be imbedded. You would have exactly the same condition as far as heat distribution is concerned.

MR. REED:—But you would not get the same electromotive force.

MR. MAILLOUX:—Then it is not altogether the difference of temperature that produces the electromotive force. That is the point on which I wished more light.

MR. REED:—It is a different kind of junction. The thermo-electric power of a couple consisting of an electrolyte and a metallic conductor is very different from the thermo-electric power of a junction consisting of two metals.

Now I will ask Mr. Mailloux if he will be kind enough to come and read the voltmeter, which is the only instrument I have here convenient, to take these measurements. The liquid is now approaching redness.

THE CHAIRMAN:—I should like to ask Mr. Reed what variations he found with different electrolytes. Is the difference very pronounced?

MR. REED:—Very pronounced. In electrolytes which consist of aqueous solutions, such as those experimented upon by the investigators I have already mentioned, the thermo-electric power seems to be very small. In the fused electrolytes, which seem to have the very high thermo-electromotive force, it may be due to the fact that they are capable of being maintained at very much higher temperatures.

I am afraid this heat will not be enough to dehydrate the liquid. I cannot get it hot enough to show in this light any difference of temperature between the two rods as indicated by their appearance. In fact I have not got it hot enough yet to actually fuse the electrolyte around those rods.

THE CHAIRMAN:—What voltage did that show?

MR. MAILLOUX:—Two one-hundredths.

THE CHAIRMAN:—What voltage did you expect, Mr. Reed, if you got the full heat?

MR. REED:—If you get the full heat and get it rapidly you get about nine-tenths of a volt.

MR. MAILLOUX:—It jumps to about two-tenths. [Position of rods now reversed.] It reverses now to about four one-hundredths.

THE CHAIRMAN:—Those rods are similar, are they, Mr. Reed?

MR. REED:—Yes, sir. We now reverse them again.

MR. MAILLOUX:—It comes back to zero. Now it is at zero, passes zero. It is now about .04, .06, .1, about .2, .18—back to zero.

MR. REED:—I think that is as much as we can get with this source of heat. In order to show this successfully the source of heat must be such as we can control to get any temperature needed. In making experiments, with the voltmeter in circuit, of course we have a battery on closed circuit. While there would only be one or two milliamperes flowing through this instrument, we must remember that the battery has a very small surface, and considering the surface it is a large current. In similar experiments after leaving the voltmeter switch closed some time the

solid cylindrical rod appeared after washing, to be of a dark blue color, due to the presence of reduced iron, while the head of the other rod is covered with spots of a bright red color, evidently ferric oxide. That result, of course, would be due to the passage of the current which would oxidize this electrode, and reduce iron upon the other. In order to get satisfactory results, we must have heat enough so that the electrolyte will act to a considerable extent upon the iron cup and dissolve a sufficient amount of iron in the solution to allow the current to pass without polarization with this instrument. I am sorry to say that I am not able to get heat enough. The pressure of the gas here is much less than where I have been experimenting. I will try this once more. [Changing position of lamp]. It may be a little hotter.

MR. MAILLOUX:—It is .04—about .06.

MR. GEO. F. ATWOOD:—I would like to ask Mr. Reed if the electrolyte undergoes any change with the continuous discharge of current.

MR. REED:—Certainly. The slightest current must produce a chemical change

MR. ATWOOD:—I meant to ask if the electrolyte loses power and becomes weakened and has to be replenished.

MR. REED:—Yes. As soon as the iron or other impurities capable of undergoing oxidation and reduction are entirely gone from the electrolyte, then no further current can pass without the reduction of some other constituent of the electrolyte, such as sodium or hydrogen. They would be the only two present capable of reduction, and that reduction requires the absorption of considerable energy. In other words, it would act as a counter-electromotive force or polarization. Does that not answer the question?

MR. ATWOOD:—Yes sir; that is the point.

MR. REED:—We are not able here to get heat enough to bring the electrolyte up to the proper condition. If you will turn in the paper to Figs. 10 and 11 you will see that the change in electromotive force is only a few hundredths of a volt until the temperature reaches in the neighborhood of 550°, and we have not got anywhere near that temperature here. At that temperature there was a sudden change, the direction of the current reversed; that was at the end of forty minutes in that experiment. (Fig. 10). You will see the line where it says "color turns brown." The temperature there is nearly 540°, and at that point this change takes place in the electrolyte, and the electromotive force then reverses and goes up very rapidly. In our experiment here we did not not get to the temperature at which the electromotive force reverses. The same thing is shown in Figs. 11 and 12.

MR. J. P. WINTRINGHAM:—The remarkable thing about these diagrams seems to me to be the very large change of electromotive force for small changes of temperature. But of course it

is the difference of temperature of the two rods which is the governing factor and not the absolute temperature of the mass.

In the first two diagrams, 5 and 6, the electromotive forces follow the temperature very closely, and then in the others and in the following diagrams they vary widely from it.

I suppose that is due to the change of the electrolyte with the brown color, and that the thermo-electric force due to the electrolyte previously and after that is very different. I was wondering if one electrode was introduced first and allowed to heat and then the other was introduced, if that would show very much electromotive force or whether it would require warming a little before the current could pass at all?

MR. REED:—A cold electrode suddenly inserted, chills the electrolyte around it and forms a non-conducting shell.

MR. WINTRINGHAM:—Then there is a question if the absorption of heat might not be due to something else besides a chemical change. In heating or cooling metals, certain changes take place abruptly in the line on a diagram showing the gain or loss of temperature against time as an ordinate.

I believe the word recalescence is associated with some such change in iron—possibly a change of molecular structure or specific heat.

MR. REED:—This is a liquid. You must bear in mind that this electrolyte is a liquid all the time.

MR. WINTRINGHAM:—I understand that, but still the great absorption of heat is not only at the melting point and at evaporation, but at other points there may be considerable absorption of heat without a corresponding rise of temperature.

MR. REED:—Then while it remains liquid, after it reaches a certain temperature, it suddenly absorbs heat without changing to the solid state.

MR. WINTRINGHAM:—I know. But there are much changes in the heating of single metals alone. If you have a rod of iron red hot, white hot, and allow it to cool, it cools off slowly to a certain temperature and then becomes hotter again, brighter, and then goes on cooling.

And then on page 297 the formula shows free oxygen. Does the chemical boil? Is there evidence of free oxygen being given off?

MR. REED:—Well, you could hardly call it boiling in the sense that water boils. There are minute bubbles of gas or steam coming off from the time the experiment begins until the end.

MR. C. P. STEINMETZ:—Reading Mr. Reed's very interesting paper, I am not satisfied that the effect described therein is really a thermo-electric effect and not electro-chemical or galvanic The abrupt change of the E. M. F. at the temperature at which chemical dissociation is shown to occur by the change of color, rather points to electro-chemical action. The magnitude of E. M. F. points the same way.

If two electrodes of different chemical affinity are inserted into an electrolyte, chemical combination takes place at the one, dissociation at the other electrode. The energy produced by chemical combination at the one electrode is greater than the energy consumed by dissociation at the other electrode, and the difference of energy appears as electric energy. As well known, chemical affinity is a function of temperature, increasing in general with increase of temperature up to a maximum and then decreasing again and reaching zero at the dissociation temperature of the compound. Thus, if two electrodes of the same material, but at different temperatures, are inserted in an electrolyte their chemical affinities are different and they thus act like two different materials, that is, form a galvanic couple and chemical combination takes place at the electrode of a temperature giving a higher chemical affinity, and an equal amount of chemical dissociation at the electrode whose temperature gives a lower chemical affinity. This seems to me the effect observed by Mr. Reed. It is thus not thermo-electric, but electro-chemical, or the same as, for instance, in a zinc copper cell, the only difference being that the chemical energy which produces the electric energy is ultimately derived from heat energy.

The cycle of matter is thus: Iron and oxygen combine at one temperature, the compound is brought to another temperature, there dissociated into iron and oxygen, and the iron and oxygen brought back to the first temperature, where they combine again. The corresponding cycle of energy is: Energy is consumed at the one temperature by dissociation, transferred by the specific heat while bringing the iron and oxygen from the one to the other temperature, energy produced by chemical combination at the second temperature and energy transferred by the specific heat of the oxide of iron when being brought back to the first temperature. Thus the difference of specific heat of the oxide of iron from the specific heat of iron and oxygen equals the difference of chemical affinities and is thus the source of energy which produces the E. M. F. The phenomenon is analogous, to a certain extent, to the pyro-electric machine, in which iron is withdrawn from a magnetic field at a temperature beyond the critical temperature, that is while unmagnetic, then cooled below the critical temperature and attracted by the magnetic field again while magnetic. Here the source of energy is the difference of specific heat of the iron in the magnetic and in the unmagnetic state.

MR. REED:—Do I understand that you admit the source of the energy is heat?

MR. STEINMETZ:—Yes, sir, the ultimate source of energy is heat.

MR. REED:—That is all I have attempted to show. Although we got only small amounts we have got some electrical energy here. I do not think there is any known process by which heat

can be converted directly into electrical energy, except by thermo-electric conversion. I think, if you look into the question carefully, that you will see that the energies exactly balance each other, which you speak of as resulting in an evolution of energy by the differences of specific heats. I admit that there are differences in specific heats. I admit that it is possible that there are differences of affinity. There is undoubtedly a difference between the affinity of oxygen for iron at high temperatures and at low temperatures. But can that difference of affinity, under these conditions, evolve energy, when we must produce the same amount of oxide of iron which we reduce. In other words, keep in mind that the amount of iron oxide reduced at one electrode is equal to the amount produced at the other, can we evolve any energy by that process?

MR. STEINMETZ:—It is this very point which I intend to explain that by combining iron and oxygen to oxide of iron at one temperature and dissociating the same amount of oxide of iron at a different temperature, more energy must be transformed in one case than in the other, due to the difference of chemical affinity, and thus an E. M. F. produced which is galvanic or electro-chemical but not thermo-electric, although ultimately due to the difference of specific heat of the compound and its constituents.

We have a double transformation: of heat into chemical energy and of chemical energy into electric energy, but no direct conversion of heat into electric energy, that is no thermo-electric effect. The process is essentially the same as for instance in the zinc copper cell where the affinity of the zinc is ultimately produced by heat also, only more efficiently by a separate process, the electro-metallurgical reduction of zinc from its ores.

MR. REED:—Assume we have an isolated system like that—suppose we take away the flame for a few moments, we have got a certain chemical condition and a certain amount of heat not uniformly distributed. Can we then by an internal process convert part of that heat into chemical energy so that in the end the chemical energy and conditions shall remain the same, and at the same time evolve electrical energy without a thermo-electric conversion when the only tendency towards any change is that of uniform distribution by conduction?

MR. STEINMETZ:—Yes, by a transfer of heat from higher to lower temperature. By changing the temperature of a compound and oppositely changing the temperature of its constituents we get less heat energy back than put in, and the difference is transformed into chemical affinity, which again is transformed into electric energy if the electric circuit is closed.

MR. REED:—In other words, it is equivalent to the theory that instead of this being a thermo-electric process it is a thermo-chemical transformation of heat into chemical energy.

MR. STEINMETZ:—Yes sir,

MR. REED:—And the chemical energy so produced evolves electrical energy, the initial and final chemical conditions being identical?

MR. STEINMETZ:—Yes sir.

MR. REED:—And that the oxidation of the iron evolves more energy than the reduction of an equal amount of iron which goes on simultaneously with it?

MR. STEINMETZ:—At the different temperatures, yes.

MR. REED:—At the different temperatures. Well, of course there is nothing in these experiments to prove that that is not true; but if we assume that, then we might apply that same reasoning to almost any chemical action. We might say a chemical action could take place in one part of an electrolyte and reverse in another part and evolve electrical energy.

MR. STEINMETZ:—It seems to me to be impossible otherwise. Since the chemical affinity is different at different temperatures, if in the same electrolyte oxidation and reduction of equal amounts of materials take place simultaneously but at different temperatures, more energy must be produced by the one than consumed by the other, and thus a difference left which is a function of the difference of temperature of oxidation and reduction.

MR. REED:—I do not see that there is anything in these experiments to disprove your theory, but I do not see anything in these experiments or in similar ones to prove it. I admit there is nothing to actually disprove that that is the process by which the heat of the flame may be converted into electrical energy. My object was, as already stated, to show that the source of this electrical energy was the heat. Now as to the processes through which the energy might pass before it becomes electrical energy, of course, it is easy to assume that it may pass through a thermo-chemical process such as you have mentioned. I do not see how we could prove that that was not so. These experiments certainly do not prove that.

MR. STEINMETZ:—The ultimate source of energy is undoubtedly heat, but the electric energy is not produced by heat, but by chemical action of matter just as in any galvanic couple.

MR. REED:—I think there is one evidence against that theory. It is that chemical affinities do not act in that way. Chemical affinities do not depend on differences of temperature. Under a given pressure a chemical reaction takes place at a given temperature and continues as long as the products of the reaction do not interfere. The energy evolved by a chemical reaction does not increase with the temperature at which it takes place But the experiments of Bouty, Chroustchoff, Sitnikoff and Carhart all show that the electromotive force increases with the absolute temperature according to the formula for thermo-electromotive force determined by Kelvin and Tait for metallic conductors. If chemical affinity causes this evolution of elec-

trical energy and absorption of heat, we should, after reaching a certain temperature, be able to convert any quantity of heat into electrical energy.

MR. MAILLOUX:—I think that we are mostly wrangling about definitions in this matter. Our knowledge of chemistry has been progressing somewhat as a consequence of the work done by such men as Berthelot, Julius Thomson, and others, who have done so much in the field of thermo-chemistry. To-day there are chemists who tell us that oxidation and all cognate chemical phenomena are nothing more than thermo-dynamical phenomena; that the reactions which take place therein are functions of change of volume and of internal stress; that, in a word, we are dealing with a problem of thermo-dynamics pure and simple, in nearly all if not in all chemical reactions. When we heat a substance it changes in size, in physical condition and in temperature. A part of the heat which it absorbs goes to dilate the body, and becomes latent. It does physical work against some resistance, probably purely mechanical, inside the molecule. It is the intrinsic energy absorbed by the body itself in overcoming atmospheric pressure or its own molecular elasticity, or in causing changes of internal stress. A portion of the heat energy remains available and ready to do work. It may be provisionally locked up and may play a part in certain internal phenomena in the molecular structure just referred to, but upon proper conditions being established that energy is immediately restored and can do work outside of the molecule from which it has been released. Many chemists believe to-day that we shall soon have to treat chemical reactions as problems in physics. Even the word molecule is looked upon with suspicion. We are coming soon to a state when the advance in the science of thermodynamics will give us all the information that is necessary to explain chemical phenomena. Some ten years ago, in a lecture before the Franklin Institute, I called attention to this fact, and I ventured to express the belief that the changes in volume of the chemical substances in the electrolytes and in the plates in the storage battery are a criterion of the electrical phenomena involved and probably will be made a measure of it; and that, in general, the amount of energy necessary to change the volume of a chemical substance can be measured by the change in volume and internal stress. It seems to me that in this instance we are dealing with a case where we put energy at the heat end, some of which is necessarily absorbed and stored in dilating the substance, or in other internal physical changes or reactions (so to speak, for want of a better term), while a portion of it is available for other purposes. At the time that we unlock this combination of heat with a body (which chemists call an oxide or any other compound—it is merely a substance which has undergone change of volume by reason of energy which has been put into it), that is to say, when we make the transfer of energy, and bring back the substance to

its original volume and to its original state, if we do it at a lower temperature, it is evident that the mere change of temperature makes a difference in the intrinsic energy of the body; just as much as there is a difference in the heat energy necessary to dilate a pound of water at 100 degrees and at zero degrees centigrade. So it seems to me that in this instance we have a great deal of energy which is not at all chemical. It is merely physical energy involved in the change of the molecular volume of the substance. Faraday's law tells us that the amount of electric current due to the transformation of iron into oxide and of oxide into iron again must be the same, yet it is done under different conditions of electrical pressure, if that pressure be due to molecular changes, whether it be due to the heat itself, or whether it be due to any other physical condition produced by the heat, there must necessarily be a change of energy, a difference in energy. I believe that the phenomenon is merely one in which we have changed the volume or the internal stress by changing the temperature, and that that energy is the very one that enters into play and is rendered available as electrical energy. I do not think that my explanation is as clear as it might be, because this is a problem on which most of us are still largely in the dark. I have tried simply to convey the idea, that in chemistry we are dealing largely with thermodynamic phenomena, and that in this case we are probably dealing with a thermodynamic phenomenon in wich a transfer of energy takes place from the hot to the cold body, or vice versa, according to the case, merely by virtue of the change of volume, or of internal stress caused by the heat.

Secretary Pope:—It is getting late, but I am sure we would all be glad to hear a word from our distinguished foreign member, Mr. W. M. Mordey, who is with us this evening. I believe he has a point which he wishes to clear up, and at the same time he might perhaps elucidate some of the points that have been raised in this discussion.

The Chairman:—We should be very much pleased to hear from Mr. Mordey.

Mr. Mordey;—As I came in late I did not have the advantage of hearing the paper read. There is one question I wish to ask, but before doing so I will say, as this is the first occasion I have had the honor of being at one of your meetings, although I have been a member a few years, how very glad I am to be a guest at this meeting and how much I feel the advantage of being a member of this Institute. I have looked to this Institute to keep me acquainted with progress on this side and I have admired the energy and ability with which the proceedings of the Institute have been conducted. By the papers you have read here and the discussions, and the way in which they are presented in the Journal, I think you have set an example to our older institution on the other side which we might very well

follow. In fact, I have often thought that you show the evidence of youth and virility on this side in your electrical institution as you do in other ways. Before asking the question, if the author would permit a moment, I would like to take the opportunity of saying how much I appreciate the great kindness that I have received, the hospitality and attention I have received from my fellow electrical engineers in all parts of the country during the visit of some five or six weeks I have been making here—a most instructive visit to me—and I have been very glad to renew my acquaintance with a good many members and to make the acquaintance of others.

The only question I wished to ask here was as to whether the arrangement of Figure 1 was not merely an arrangement for getting a difference of temperature between the two rods and whether any other arrangement by which he obtained the same difference of temperature would not have the same effect; whether, for instance, if he had two rods, as shown in Figure 3, and he surrounded one of them by a cooling jacket of some sort, or had, we will say, a couple of small holes drilled down, and circulated water through the rod, whether he would not in that way, by getting a difference of temperature, have got another result in Figure 3, as he obtained in Figure 1 and Figure 2.

I think so far as I have been able to follow the paper by glancing through it after the reading of it was finished, and the discussions, that I would complain that the author has not given us the right title, but I think Mr. Steinmetz has indicated the explanation of his experiments; I think in using the term thermo-electric, he made perhaps a wrong use of the word that we are familiar with in another sense. In a thermo-electric battery we are accustomed to look for chemical action. I think the whole of the author's experiments are to be explained on the supposition that he has by difference of temperature, chemical actions set up—the difference of temperature in one to be more susceptible to chemical action than the othor. The paper is thoughtfully written, and I have no doubt that the author has made a great many experiments that are not detailed here, and possibly he has made an experiment such as I suggest in the cooling by artificial external means of the two electrodes. I would ask; if he has done so, whether he has not found the difference of potential that he got in the arrangement shown in Figure 2.

MR. REED:—I would reply that I have made those experiments and found in all cases that any means by which we can maintain a difference of temperature between the two electrodes will give the result. Liebenow and Strasser, in their paper previously referred to,, repeated an experiment which I tried a year or so before, and described in another place, of using two iron tubes bent—U tubes which were dipped into the electrolyte, one being kept cold and the other hot by a stream of air or a liquid,

and they reported that a difference of E. M. F. of about one volt was obtained in that way. The only object of presenting this in this form was, as I thought, to get an arrangement in which there could be no doubt whatever that the E. M. F. was due solely to a difference in temperature between the two electrodes. In other words, that it could not be maintained that in these experiments it was due to the fact that one electrode was near the surface of the electrolyte and the other deeper down, as was claimed by Liebenow and Strasser. That was their explanation. As a matter of fact, as stated in the paper, an electromotive force of about a volt can be obtained between the iron cup and the iron rod inserted when the rod actually rests on the bottom, metallic contact being prevented by a thin film of oxide or of the electrolyte. The object of this arrangement was merely for that purpose.

MR. STEINMETZ:—I do not agree with the last objection of Mr. Reed to my explanation, that the process would be continuous and contradict the law of conservation of energy. Since the difference of electric potential is due to difference of chemical affinity caused by difference of temperature, it ceases as soon as the temperature has become uniform, that is, heat has ceased to flow from higher to lower temperature.

THE SECRETARY:—Before we adjourn, I would like to move a vote of thanks to the author of the paper for the trouble he has taken in showing these experiments, and to express our regrets that the quality of our gas is not equal to the municipal gas they formerly had in Philadelphia.

[The motion was seconded by Mr. Steinmetz and carried and the meeting adjourned.]

[COMMUNICATIONS RECEIVED SINCE ADJOURNMENT.]

MR. J. P. WINTRINGHAM:—The writer of this paper seems to be unusually well informed and to have given a good deal of thought to the subject. I suppose he had only one object in view, to establish the seat or origin of the electromotive force. This, he argues, is due to a thermo-electric effect between iron and an electrolyte, melted caustic potash. Incidentally he claims that melted potash must conduct electrolytically. Yet many insulators allow a current to flow when highly heated and generally their resistance decreases with a rise in temperature. His argument is that heat of combination of the iron is always a constant quantity and the electromotive force cannot be due to the chemical affinity which is measured by the heat of combination, for an absorption of energy would take place at one pole equal to that given off at the other, so no electromotive force can be attributed to that source.

I think it must be admitted that chemical affinity does vary with the temperature. What seems still to be wanted is a crucial experiment that will show what the source of the electromotive force is. I can only suggest that the differences of the temperature of the rods should be measured, and plotted against the voltage measured by an electrometer so as not to allow of any flow of current. If such a curve approached a straight line or was free from abrupt changes it might be judged that the voltage was caused by a thermo effect and not by chemical affinity.

MR. C. J. REED:—In view of the foregoing discussion and the consensus of opinion that the energy of this cell is derived entirely from the external heat, and in view of the suggestion by Mr. Morday that I have merely made a mistake in the title of the paper in calling the cell thermo-electric, I believe it might have been conducive to a clearer understanding of what this apparatus was intended to exhibit, if, instead of a thermo-electric battery, I called it "*a novel form of galvanic battery, in which the only source of electrical energy is external heat absorbed by the circuit while it is in action.*" The importance of distinguishing between a galvanic battery of this character and a thermo-electric battery did not occur to me until after reflecting on the arguments presented at the meeting. My reason for calling the action of such a cell thermo-electric was that it has heretofore always been recognized as such, and because no process, except thermo-electric inversion, has yet been defined, by which external heat is absorbed directly into an electric circuit and simultaneously evolved as electrical energy. What name shall we give to the new process?

DIED.

EMERY:—In Brooklyn, N. Y., June 1st, 1898, Charles Edward Emery, Ph.D., Consulting Engineer. Dr. Emery was born at Aurora, Erie Co., N. Y., March 29th, 1838. He was educated at Canandaigua Academy, and was engaged in the regular U. S. Naval service as an engineer from 1860 to 1868. He was elected an Associate Member of the INSTITUTE, June 26th, 1891, and transferred to Membership April 19th, 1892. He was appointed a member of the Board of Examiners, October 23d, 1895, and was Chairman of that body at the time of his death.

GOTT:—In New York City, Monday, June 6th, Clarence P. Gott, formerly Chief Engineer and Electrician at the Grand Central Palace. Mr. Gott was elected an Associate Member of the INSTITUTE, November 20th, 1895.

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